Agroforestry Systems in China

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FOREWORD

Agroforestry or farm forestry is a production technique or method that combines agriculture and forestry on same piece of land to fully utilising the natural resources of sunlight, water and nutrition. By following this method, the farmers get income both from agricultural and forest products. This farming skill has been expanded on a large scale to promote the development of landuse systems and to meet the social requirements. It has special meaning to bring a balance between limited land resource available and to grow enough food to meet the needs of increasing population.

Agroforestry has a long history in certain areas in China. According to Chen Yung (1943) "History of Forestry in China and Administration of the Republic", agroforestry was practised 1,700 years ago in Shanyang County. Zheng Hui, a civil officer, found that the local farmers experienced great shortage of timber. Therefore he called for planting elm trees around the farmland to build a living fence. After certain period, uniform elm tree belts developed that not only provided enough timber to meet the local requirement but also were beneficial to the growth of crop plants.

It is recorded that it was 300 years ago that forest farmers intercropped agricultural crops under young plantations of Chinese fir in Southern China and this practice has been reintroduced recently in Southeast Asia described as Taungya System.

Of late, many countries face the problem of diminished arable land and the needs of population. To increase production, agroforestry development seems very important. As the development of a new branch of science, agroforestry has an important role to play in modern production technology. From a combination of primary production of agricultural crops and forest trees, it has become an integrated artificial ecosystem consisting of not only primary produces, but also includes secondary production components such as animal husbandry, fishery, sericulture and apiculture. In this type of diversified management system, optimal economic, ecological and social benefits can be obtained. Fish pool with mulberry trees planted around practised in Guangdong Province of China is a typical modern agroforestry system.

Agroforestry is a production system of artificial plant communities. It also includes fishery and animal husbandry. The main attention should be devoted to explore the relationship between plant, animal and the environmental factors when studying this integrated production system. For the comprehensive research, ecology, plant physiology, agrometeorology, soil science and other basic sciences and practical techniques related to agronomy and silviculture must be mastered and adopted. In order to select suitable plant material for an agroforestry system, besides fully using currently available varieties or cultivars of crop plants and forest trees, it is also important to explore new sources through plant breeding and other improvement programmes. For this purpose, the knowledge of genetics and plant breeding is very important. Plant protection and use of agricultural machinery are also helpful to promote the productivity of agroforestry system. For development of integrated farming system using animals, application of new methods and skills related to animal production are necessary. As a scientist working in the area of agroforestry, one must have wide basic knowledge. To a certain extent, the success of research on agroforestry depends on the organisation of scientists with multi-discipline approach. From this point of view, the IDRC-supported "Farm Forestry (China) Program " is a good example and will play an important role in the development of China's farm forestry development.

In this proceedings, the major agroforestry models followed in China are outlined. Under the support of IDRC, the publication of this volume will be a great contribution to help the understanding of China's agroforestry by other scientists outside China.

Wu, Zhonglun
President
Forestry Society of China

PREFACE

In this technological age, it is becoming increasingly clear that if man is to survive on this planet much time and energy will have to be spent to devise many agricultural and forestry production methods with good land management practices. Agroforestry system is one such practice.

Agroforestry includes different methods and techniques to grow suitable trees and crop plants together on the same plot of land. The practice of Agroforestry also reveals the harmonious growth of certain plants and animals that the cultivated field can support. There must be a significantly positive interaction between the trees and herbs or shrubs used in the system. Proper use of land will increase the sustainable production year after year. Considerable economic gains have been obtained in many countries by practicing agroforestry which depends on the suitable combination of soil conditions, types of plants growing, their spacing, water availability etc.

In China, there is a shortage of cultivated land and the country has sparse forest resources and there is a great demand for timber and fuel wood. Better utilization of wood is desired since leaves and twigs are gathered for fodder and fuel. Many big forestry projects are undertaken to meet the increasing wood shortages.

IDRC's support for forestry resource in China was started with a bamboo project in 1981. Since then, more than 72 projects are supported with the finance of CAD 10 million. The outcome of these projects have brought good results and great benefits to many people including the scientific man power development in various institutions. Many of the scientists involved with the project work received their training abroad. In line with the above, the support given for agroforestry research was also well utilised. Paulownia plantations developed extensively in many parts of China and with good intercropping, the revenue per given plot of land increased by 15-30% more than the control.

Besides recording the history of Agroforestry in China, this volume discusses the combination growth results of different trees like Elaeagnus, Eucalyptus, Fraxinus, Hevea, Paulownia, Populus, and other crop plants like rice, wheat, tea, mulberry, medicinal plants, mushrooms and others. The improvements envisaged in physical and edaphic conditions along with crop yield, wood and biomass production are enumerated. Covering the sand dunes with plants and impeding their movements, growing fish or lac producing insects, raising the bee hives are other important agroforestry contributions included in this publication which serve as good examples worth emulating under similar conditions both within and outside China. Altogether, there are 38 papers presented under five sections.

It is very much hoped that this publication, which may very well be one of the few published from a developing country, will be well received by researchers in agroforestry working in other developing countries. There is every good reason to believe that many of the methods outlined can be easily followed with certain modifications to meet the local conditions in other countries. If the projects are well executed, they would help to meet the short fall of food, fibre and fuel.

Lastly, it is a great pleasure for me to thank Drs Derick Wedd and A N Rao for their invaluable help, in bringing out this publication.

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I. OVERALL STUDY ON AGROFORESTRY SYSTEMS IN CHINA

Agroforestry in China - An Overview

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Introduction

China is a vast country. Its land area covers about 9,602,700 km^2, of which 100,000,000 ha are arable while another 115,000,000 are forested. The country has a population of well over one billion people, 80% of whom are peasant farmers living in villages. Given the size of the population and the limitation of arable land, a villager in China has less than 0.13 ha land for himself, and this availability shrinks further to less than 0.03 ha in densely populated areas. Similarly in terms of wood availability, the standing volume of timber is about 10.3 billion m^3, or about 10 m^3 per person.

China launched its four modernisation programmes about a decade ago. This has resulted in increased industrialisation activities with a consequent increase in demand for timber and energy which has led to an increasing pressure on land. Rapid and over exploitation of forested lands has led to increased soil erosion, increased run off, siltation of the rivers, flooding and droughts. The most heavily eroded regions (about 280,000 km^2) lie in the middle reaches of the Yellow River at the Loess Plateau where the forest cover is less than 4%. The silt flowing through the Sanmen gorge of this river amounts to about 1.6 billion tons per year which is estimated to raise the river bed at the lower reaches by 10 cm annually. The siltation is also known to affect the storage capacity of the reservoirs along the river.

Investigations carried out on seventeen of the twenty biggest reservoirs along the Yellow River Basin indicate that they receive a deposit of about 6 billion m^3 or 60% of their total storage capacity. It is also estimated that the run off carries with it approximately 30 million tons of nitrogen, phosphorous and potassium. This type of equally alarming situation also exists along the Yangtze River, China's biggest river. Here the silt from soil erosion amounts to about 640 million tons per annum.

It is obvious that for China to maintain its momentum of modernization as well as to meet the aspirations of her people, urgent remedial measures need to be adopted to enhance land utilisation. This should also include greening China's 1,280,000 km^2 of deserts in the North western region as well as preventing further desertification. It is estimated that about 6,700,000 ha of farmland and a similar area of pasture land over 200 counties in this region is vulnerable to calamitous sandstorm. For instance, desertification in the Inner Mongolia Autonomous Region has doubled from 7,330,000 ha to about 10,670,000 ha between 1960 and 1977.

The country's timber supply is also very short of satisfying demand. Partly indiscriminate exploitation of forest resources in the past, for wood, fodder and energy, has left vast areas of China devoid of vegetation. Urgent measures are needed and are being taken to reforest the country. Annually an average of 3 million ha of land is afforested, still the country is dependent to a large extent on imported timber and pulp to meet domestic demand.

To solve this increasingly difficult situation, the Government of the People's Republic of China has been taking a series of measures. These measures are meant to help arrest the irreversible effects of soil erosion, siltation, flooding and desertification. Policies have been designed to enhance the farmers' ability to produce more food, to put the land to multiple use including the planting of forest trees that are multipurpose; to afforest the denuded and wastelands that lack agricultural potential, to expand forested areas for purposes of conservation, shelter, catchment and arrest desertification.

Part of this policy also lays emphasis on combining agricultural and forestry crops together. Chinese farmers and scientists are working together to identify appropriate species combinations, management techniques, agronomic practices and protective measures to increase the yield of the land. In China such plantation technologies go under a variety of names. These include terms like 'stereoscopic agriculture', 'stereoscopic forestry', 'multiple ecological system of agriculture and forestry'. All these terms are synonymous to 'agroforestry' and the terms are meant to name a farming system or an 'artificial' agroecosystem serving certain ecological and economic purposes. Its aim is to provide the best ecological and economic benefits to the farmer.

Even if the terminology used in China is different, the practice of this kind of plant culture forms the 'sustainable land management system that increases the yield of the land, combines the production of crops (including tree crops and forest trees) and/or animals simultaneously or sequentially on the same unit of land, and to promote appropriate management practices that are compatible with the cultural practices of the local population' (King and Chandler, 1978).

There is enough evidence in literature to suggest that forest trees and agricultural crops can be grown together without deterioration of the site. For example, in the taungya system described by Blandford (1958), there seemed to have been ancient cultural practices whereby some societies simulated forest conditions on their farms in order to obtain the beneficial effects of forest structures. Also the evidence of Fisher and others (1976) suggest that mixed cropping of annual crops is often a more efficient means of utilising land than pure stands. The rest of this paper describes a few Chinese models of agroforestry.

History of Agroforestry

One form or another of agroforestry has been practised in China since ancient times. During the Han Dynasty (206 B.C. - A.D. 220), administrators recommended the development of forests together with the raising of livestock and crops according to different site conditions. Many successful agroforestry systems have been in practice, some of which have developed very fast throughout the country since new China was established. It has been shown through scientific research and farmers' practices in China and elsewhere that agroforestry systems have many advantages with a bright future.

In the Northwest, North Central and Northeast of China (abbreviated 'Three Norths'), a programme of developing a large-scale shelter belt system has been started, known as the 'Green Great Wall' programme. Its objectives include rehabilitation of wasteland, development of vegetation for the control of sandstorm, as well as soil and water erosion control through large-scale afforestation and grassland development. It started as an agroforestry system in 1978, as perhaps the biggest programme in the world. It is scheduled to be completed at the turn of this century. The Government allocated $72.2 million USD during the past seven years, as a special fund for the development of the shelter belt system; another $243.3 million USD had been raised from other sources through either state or local channels. During the first phase (1978-85), 12.8% of farmland shelter belts, 23.2% of dune-fixing forests, 55.3% of soil and water conservation forests and the remaining 8.7% of other types of forests were expected to be established. As a result, 6.7 million ha of farmland and 3.4 million ha of pastures have been protected. Soil and water erosion in some of the areas has been partially controlled and the insufficiency of fuelwood partially solved. Now this programme is conducted very successfully.

Today, there exists an initial system of farmland shelter belts stretching over 440,000 ha through thirty-nine counties in the Ningxia Hui Autonomous Region and Inner Mongolia Autonomous Region; and 600,000 ha in Xinjiang Uygur Autonomous Region. It is reported that areas under the protection of shelter belts are capable of producing higher crop yields of superior quality. Yield increases average 16.4% for maize, 36% for soybean, 42.6% for sorghum and 43.8% for millet. In areas with critical problems of soil and water erosion, activities aimed at comprehensively managing small-watersheds have been undertaken. Planting trees and grasses coupled with the building of checkdams, dikes and terraced fields are some of the various forms of control measures effected over 8.2 million ha of eroded land. Similarly, in areas with serious problems of strong winds and sandstorm, efforts are being made to rehabilitate them with shrubs. Today, as a result, 367,000 ha are basically improved, and 35,000 ha already been brought under the plough.

The plains are centers of agricultural production in China, constituting about 10% of the country's total land area or a total of 40 million ha of farmland. Living on these plains are 350 million people. The main forms of agroforestry are:

(a) farmland shelter belt and forest networks
(b) intercropping agricultural crops with trees
(c) planting trees around houses, along roadside and river banks etc.

The farmland shelter belts are usually built together with roads and channels. Their sizes vary from 6-20 ha, most of which are narrow-spaced forest shelter belts. Statistics show that 643,000 ha of farmland shelter belts have so far been built and 10.73 million ha of farmland are brought under protection, with these systems having produced a large amount of timber and fodder. Such farmland shelter belts have been widely used in the North and Northeast of China as well as in parts of the southern subtropical areas.

Several systems of intercropping agricultural crops with trees have been practised in the plains, over an area of more than 2 million ha. The main forms of intercrop are agricultural crops with *Paulownia*, date, fruit tree, willow, false indigo and white mulberry. This type of vegetation can be efficiently used either for control of soil or wind erosion or to use as organic fertiliser or fodder and to grow fruits. Intercropping agricultural crops with *Paulownia* trees has been extended over 1.3 million ha of land. In some lower districts of the Yangtze River Delta and Zhujiang Delta, forms of agroforestry such as cultivating agricultural crop trees or medicinal herbs or to develop fishing areas are being tried.

Planting trees around houses, villages, along roadside and rivers is another common type of agroforestry in China's plains. According to statistics, 7.2 billion trees have been planted in the plains, among which 5.8 billion are planted around houses and in villages, with each peasant household having an average of 74 trees. This amounts to 10-15% of the total area of plain land in rural parts. It can be said that each village is just like a 'village forest farm'. Besides producing a certain amount of timber, other associated activities that have emerged are animal husbandry, floriculture, and fishing industries. The peasant is thus managing intensive multiple use of the small area of land around his house. He may derive an income of more than 10,000 Chinese Yuan (RMB) from a garden of less than 0.02 ha.

In China's hills and mountain areas, other types of agroforestry are practised as site conditions vary from place to place. Widespread among these practices with a rather long history and covering a big area is intercropping agricultural crops with trees such as *Aleurites fordii*, *Sapium sebiferum*, *Juglans regia*, *Castanea bungeana*, *Camellia oleifera*, *Camellia sinensis*, *Hevea brasiliensis*, *Diospyros kaki*, and *Fraxinus chinesis*. Successful trials have been conducted to plant traditional Chinese medicinal plants such as *Panax ginseng* in the Northeast, *Coptis chinensis* var. *brevisepala*, *Amomum villosum*, *Gastrodia elata* in the Southwest; and some edible fungi such as *Auricularia*, *Tremella*, *Dictyophora indusiata*, *Lentinus edodes* and *Pleurotus ostreatus* under various types of forests, such as bamboo forests that have shown a great production potential.

Recently, agroforestry has been receiving more and more attention in China. It has been studied by many categories of scientists from their respective perspectives, namely - forestry scientists, agriculturists, animal husbandry scientists, hydraulic engineering scientists, agro-meteorologists, ecologists and socio-economists. A workshop on Agroforestry was held by the Ecology Committee of the Chinese Society of Forestry in October 1986. More than 500 papers on agroforestry have been published so far.

Under the Chinese Academy of Forestry, the Research Institute of Forestry, the Research Institute of Subtropical Forestry, and the Research Institute of Tropical Forestry all have their own projects in agroforestry, some examples include:

(a) the 'Three North' Shelter Belt System Engineering;
(b) the Plain Farmland Shelter Belt System;
(c) intercropping agricultural crops with *Paulownia*, Chinese date, *Aleurites fordii*; and
(d) cultivation of *Dictyophora indusiata* under bamboo grove.

Several national forestry research institutes and universities have also participated in these studies. For instance, the Nanjing Forestry University has a project in Lixiahe district of Jiangsu Province, regarding agroforestry multiple ecosystem and pine plantation with tea cropping. The Academy of Sinica studied agroforestry in Yunnan Province, and mulberry plantation with fish farming in Zhujiang Delta. The International Tree Crop Institute, China Office was established in October 1986, located at the Chinese Academy of Forestry, Beijing. It will play an important role in the development of agroforestry in China and in international cooperation in agroforestry.

New and Highly Promising Agroforestry Systems

This part of the paper will now elaborate on seven agroforestry systems currently in practice:

1. Intercropping agricultural crops with *Paulownia*;
2. Intercropping agricultural crops with Chinese date;
3. Artificial agroforestry multiple ecosystem in Lixiahe flatland;
4. Multiple layer artificial population in Yunnan tropical area;

Table 1a. Change in soil and chemical properties after intercropping with tong trees

Treatment	Organic Matter %	Total N %	Total P %
Before intercropping	1.23	0.041	0.008
Intercropping for 1 year	1.75	0.066	0.011
Intercropping for 2 years	1.99	0.07	0.009
Intercropping for 3 years	2.09	0.097	0.010
Beginning intercropping at 4th year	1.82	0.063	0.011
Beginning intercropping at 5th year	2.10	0.066	0.012

5. Forest-grass system in North Western Loessial Plateau and desert area.
6. Intercropping models in subtropical forest region. and
7. Garden type agroforestry.

Intercropping Agricultural Crops with *Paulownia* sp. -

This system has been used and expanded to approximately 1.3 million ha and now become an important cultivation system in flatland of North China. *Paulownia elongata* is one of the fastest-growing trees in this region. About 0.5 m^3 volume of timber can be harvested from a ten-year old individual tree. *Paulownia* possesses some traits that are good for intercropping such as a deep root system (40 cm), leaves grow late, and there is a more transparent crown.

In sandy and loamy soil approximately 75% of the root system is found in depths of 40-100 cm in contrast to wheat, millet and maize where root systems rarely grow below 40 cm. This simply means that there is minimal competition between roots of trees and crops. In drier seasons, *Paulownia* absorbs underground water from the deeper layers that helps in humidifying the moisture content of upper layers.

Interplanting *Paulownia* in agricultural fields generally seems to enhance the suitability of the microclimate for agricultural crops. Experiments showed that wind speed was reduced between 21-51%, evaporation rate was about 9.7% during the day and 4.3% during the night, the moisture content of the upper layer of soil increased as much as 19.4% and air temperature went up by about 0.2-1°C in winter and down between 0.2-1.2°C in summer in the day time. There was also a strong trend of increased yields in agricultural production. Wheat increased between 6-23%, millet by about 20% and maize between 7-17% (Anon, 1986). *Paulownia* can be planted in different density spacings (5 x 10 m - 5 x 40 m). The tree has played a notable role in alleviation of natural calamity caused by early summer's dry-hot wind and drought, thus ensuring high and stable yields of crops, the economic benefit of which increased by 15-25% when compared to single stand crops.

Intercropping Agricultural Crops with *Ziziphus jujuba* (Chinese Date) -

This 'date' is a nut tree species popular in China, thriving from temperate to subtropical areas. The Yellow River -Huaihe River plain is its center of distribution. Jujube fruit is rich in vitamin C (380-600 mg/100 g), content higher than in apple, highly nutritive, and its flower nectariferous. It is reported that 1,500 kg of honey can be collected from one ha of intercropped land. It is an ideal intercropping tree species, for it does not deploy leaves until the first ten-day period of June. It also has a thin crown. Intercropping space between two sprouts can be 3-6 m x 6-12 m. Jujube enters the fruiting stage when it is about ten years old, and the average yield can be 6,000 kg/ha. In an intercropping system, mixed planting of the date with wheat results in the increased yield of both. The yield of intercrop wheat can reach 3.8 ton/ha, which is higher than that in a pure stand. As a result, the economic benefit increases by more than 100%. Intercropping with jujube has now exceeded 7,000 ha of land area.

Artificial Agroforestry Multiple Ecosystem in Lixiahe Flatland -

The Lixiahe flatland lying in the coastal belt

Table 1b. Change in physical properties of soil after intercropping with Tong Trees

Physical Property	Before intercropping	Intercropping Period (Year) 1	2	3	4	5
Specific gravity (g/cm^3)	1.34	1.120	1.04	0.96	1.01	0.98
Porosity (%)	50.80	50.80	61.90	65.10	63.20	64.30

receive deposit silt from Yangtze River and Huai River. The total area is 1,165 km^2, out of which a major portion has not yet been utilised. It has been demonstrated that models such as forestry plus agriculture, forestry plus agriculture plus fishery, and forestry plus animal husbandry are the most appropriate ways to utilise land resource in this region. The flood resistant tree species *Taxodium ascendens* and *T. distichum* are now the most popular tree species planted there. Intercropping crops on forest glades, pisciculture in rivers, ponds and penstock, and growing hydrophilic crops such as fodder and lotus rhizome all sum up to the agroforestry system where one component symbioses with another. Consequently, the ecosystem gets improved and the economic benefit derived increases by as much as five-fold at some sites when compared with monocrop farming. A ten-fold increase in the yield of firewood, has been observed when compared to unexploited waste-land.

Multiple Layer Artificial Population in Yunnan Tropical Area -

At Yunnan Xishuangbanna Center for Tropical Forest Research, scientists have been able to develop stereo-population models after having studied the ecological and economical profiles of various trees and crops. In this regard, it can be noted that the yields of tea and traditional Chinese medicines are increased. Experiments have indicated that *Cinchona ledgeriana, Coffea* spp., *Rauwolfia yunnanensis* and *Cinnamomum cassia* can grow under a crown where the shade density is below 0.7^o, and their yield and quality can exceed that of pure tea and drug plant plantations. The rubber tree and tea combination, or the rubber tree and camphor tree plus tea tree combination are the best patterns. In forest land, the yield of tea increases by an average of 412.5 kg/ha, with the quality being much better. Similarly, the yield of *Cinchona ledgeriana* planted in rubber tree stands (shade density 0.3-0.7) is also increased. In multiple layer population, the yield from the rubber tree is also found to be higher than that from the pure rubber stand.

The Forest-grass System in North Western Loessial Plateau and Desert Area -

In this area, owing to the arid climate, serious damage occurs to the vegetation cover. There is a shortage of fuelwood, forage and timber. The policy now is to develop a forest-grass structure combining high forest and shrubbery with grass, so that soil can be conserved, thus maintaining soil fertility, and attenuating the problems of lack of fuelwood, timber and fodder. The main tree species are *Elaeagnus angustifolia, Lycium furcomanicum, Populus sp., Lamarix chinensis, Canagana korshnskii, Hippophae rhamnoides*; and other species are *Astragalus adsurgens* and *Medicago* sp. The forest-grass species are also successful both in terms of ecology and economic benefit.

An Intercropping Model in the Subtropical Forest Region -

The subtropical area is vast in China. There are many types of timber forest and economic forest as well as varied and interesting forms of agroforestry. The latter can be altered following variation of time and shade density of the super tree. For example, Chinese fir is a main timber afforestation tree species, in its first three years of growth, some crops such as corn, potato, bean or peanut can be undersown. When the young forest develops into crown closure, the traditional Chinese medicinal plants such as *Coptis chinensis* can be planted. Some Chinese fir forests are first mixed with tong oil trees, previous to intercropping with *Coptis chinensis*, or *Amorphophallus rivieri*. To intercrop agricultural crops with tong tree is a rather common practice in hilly areas. Tong tree is planted in level terraced fields on the hill slopes at planting distances of 6-8 m x 4 m (340-420 trees/ha), and sweet potato, beans, day lily and melon are grown on the slopes of the terraced fields. The physical and chemical characteristics of the soils have equally improved due to agricultural measures such as better fertiliser management including returning straw to fields as shown in Tables 1a and 1b.

It has also been found that tong oil yield is increased following persistent intercropping. For example, intercropping crops with tong trees for

Table 2. Yield of major crops grown in tong tree-crop intercropping system.

Crops	Peanut	Rapeseed	Sweet Potato	Potato	Water Melon	Daylily
Yield (kg/ha)	810.0	428.2	10,125.2	9,999.0	21,600.0	322.5

five years can produce tong oil at the rate of 261 kg/ha, thus showing an increase of 200% when compared to a full stand. Simultaneously large quantities of agriculture products are harvested (Table 2). Thus, output value of forest land is significantly raised. In 1981, at Fuyang's Suamgjiang village, the income from intercropped forest fields was raised to $474 USD/ha, whereas from unintercropped, the value was only $36 USD/ha. In the subtropical bamboo region, the peasant is accustomed to collecting insects (exuviae of *Cicada*) and wild fungi (*Dictyophora indusiata*) as drugs and foodstuffs, thereby increasing the economic benefit of bamboo stands. Studies are underway to improve the management of such systems for better income.

Garden Type Agroforestry -

Various models of garden agroforestry exist in the country according to the ecological, social and economic conditions of different districts. For instance, in Hunan Province (Longsan County) that is located in a subtropical zone, a farmer has planted 2,200 timber trees and fruit trees both in front and at the back of his house. Among them there are 150 timber trees such as Chinese toon, *Paulownia*, Chinese fir, plane, bamboo. Also 2,050 economic trees such as *Phyllodendron*, palm, orange, papaya, loquat, as well as many undergrowth such as pistacho tree, *Atractylodes macrocephala* and beans are grown. His annual economic income has reached 7,000 Chinese Yuan (RMB). In Anhui Province's Dangshan County located in a warm temperate zone, a farmer has planted 60 *Paulownia* trees around his house; these *Paulownia* trees are twelve years old, and their worth has exceeded 10,000 Chinese Yuan (RMB). Under *Paulownia* trees, many grapevines are cultivated, and under the grapevine-rack multi-storey rabbit-sheds were established.

The above examples show great potential for developing agroforestry in China. The government of China devotes much attention to the development of agroforestry farming systems. Some provinces have held "developing stereoagriculture conferences," the participants of which are from agriculture, forestry, animal husbandry and soil and water conservation. With increasing support from the Government for improving farmers' incomes, agroforestry in China will develop very rapidly in the near future.

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Mixed Cropping with Trees in Ancient China

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ABSTRACT

A brief introduction to mixed cropping with trees in ancient China, including principles and relationships between plants and sunlight and the interrelationship among plant species in cultivated mixed cropping systems are presented in this paper.

Key words: *mixed cropping; tree-crop; forest-agriculture; ancient China.*

Introduction

The origin of mixed cropping with trees may be traced back to the early stage of preliminary agriculture. In Southwest China a minority of people always dug holes in the forest to plant roots of tuber crops such as taro. Early in the development of agriculture in China, there was a transformation from mixed cropping to mono-cropping. Hence in ancient historical literature there are many descriptions about mono-cropping and very little on mixed cropping. These materials are classified into three categories.

Application of Principles between Plant and Sunlight in Tree-Crop Situations

An ancient agricultural book, "Chimin Yaoshu (Important Arts for the People's Welfare)" (6th c.), introduced an interesting technique on how to get vertical and uniform tree seedlings for planting along the roadside. The method was to mix seeds of the Chinese scholar tree (*Sophora japonica*) with hemp, and sow them together. After germinating, the seedlings of hemp would grow faster than those of the scholar tree, thus forcing the scholar tree to grow upright. Hemp was then harvested in autumn, while the scholar tree was left over winter, until spring of the next year, when hemp seeds were sowed again. The seedling of the re-sowed hemp would again grow faster than the scholar tree and force it to grow upright. Hemp was then cut in autumn and by the spring of the third year, all the scholar trees were vertical and uniform, suitable for planting along the roadside. This method was also used in hemp-papermulberry (*Broussonetia papyrifera*) mixed sowing, but the purpose was not to get vertical seedlings. Rather, hemp was left in the field together with papermulberry to protect the latter against the cold winter.

The application of the principle of the relationship between plant and sunlight in tree-crop mixed cropping has been handed down from generation to generation. In the late Ming Dynasty a famous book "Nongzheng Quanshu (Complete Treatise on Agriculture)" by Hsu Kunang Chhi (1640) described a kind of tree-crop mixed cropping, that was to sow soybean in the interrows of Chinese chestnut (*Castania* sp.). It said that this lead the two crops to grow competitively and make papermulberry grow upright. Sometimes, shade trees were used in tree-crop mixed cropping so as to provide shade for another crop. The typical example was tea, an ancient agricultural book of Tang Dynasty (9th-10th c.) insisted that tea must be sown under mulberry or bamboo, because tea was "very afraid" of direct sunlight.

Interaction Among Plant Species in Tree-Crop Mixed Cropping

Present research showed that plants can produce certain types of chemicals and secrete the chemicals from various tissues to form a "biochemical band". That band has a complex effect on the symbiotic plants. When two or more plants of various species grow together, their interaction may be positive or negative to each other. This phenomenon had been detected by ancient Chinese peasants and they put it into practice. For example, an old farmer's proverb said: "Fallow ground grows no weeds if planted with sesame". "Nongzheng Quanshu" (1640) recorded the technique of planting Chinese fir (*Cunninghamia lanceolata*). The first year, sesame was sown to control weeds, then Chinese fir was planted the second year, followed by millet (in the spring) or wheat (in the winter) in the interrows with Chinese fir.

The choice of crops that may or may not be utilized with mixed tree cropping varies depending on the kind of crop. A detailed description relating to this was given in an agricultural book in Yung Dynasty (13th-14th c.): "Mulberry may be interplanted with several crops: Prosomillet grown under mulberry could promote the growth of both species, but foxtail millet would have a negative effect on mulberry and promote the growth of harmful insects. Sorghum was not desired because it grew to about the same height as mulberry, resulting in each shading the other from the sun. Small bean, soybean, sesame and melons, however, are very suitable for interplanting with mulberry." Another kind of tree such as elm (*Ulmus pumila*) and Chinese tallow tree (*Sapium seligerum*) could not be utilized for interplanting because of their serious shading character. This was repeatedly warned in "Chimin Yaoshu" (6th c.) as well as in succeeding literature.

Tree-Crop Mixed Cropping

Trees were more important than crops in ancient tree-crop mixed cropping. Farmers grew trees near their houses in order to get wood to make furniture, bows, wheels, and horsewhips, saddles, etc. They also sold the wood directly to obtain money. Crops in mixed cropping were mainly for controlling weeds, promoting seedling growth, protecting seedlings against the cold winter, increasing soil fertility, etc. Food grain was limited in early growth stages of interplanting.

Discussion

Today as the forests are being destroyed and the ecological environment is getting from bad to worse, the practice of forest-agriculture and tree-crop mixed cropping in the tropical and subtropical zones become an urgent task for every country and region. Chinese traditional agricultural techniques, although they differ significantly from modern ways, are important because some of the basic ideas, especially those from tree-crop mixed cropping, can be applied even today. The information on the interrelationship between plant and sunlight, the interaction among plant species as mentioned above, are examples that do not go out-of-date. Farmers in history provided us with many "hows" but not many "whys". In this modern time of ecological worldwide stress the time to investigate the "whys" has arrived.

Oriental Values and Agroforestry Development in China

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ABSTRACT

China is a developing country, and agroforestry plays an important role in rural development. The land use form has been set up with traditional oriental values. In addition, the benefits of ecology, economics and social values have been obtained. The people in most parts of China have solved the problems of food and clothe shortages.
Key Words: *Agroforestry; thought of the orient; agriculture*

Introduction

China is situated in the eastern part of Asia. The population of China is over 1.1 billion, in the total area of 9.6 million km^2, the human population density is about 115 people per km^2. There are cultivated land areas of 0.11 billion ha (not including the land areas which are altemate planting sites for tree and agricultural crops), only 0.1 ha per person. The percentage of the land covered with forest is 12.4% as assessed by the forest resource inventory in 1987 (not including the area of agroforestry). China has some similarities with other ancient countries. For example, bare mountains and gullies on hills have been formed, and soil and water loss has become very serious. Presently in China, there are more than 300 counties without enough food and clothing. If food (food grain), energy, water and land resources, and environment are the biggest problems in the world today, it is more serious in China than in other developing nations. Concerning the bearing capacity of the land, China is in an over-saturated and overloaded state. The people in most parts of China have solved the problems of food and clothing and the living standard has been improving. Above all, Chinese agroforestry has been playing an important role.

Thought of the Orient

After man learned to use fire, there appeared some obvious differences between mankind and other living things. Gradually, people started to master cultivation techniques, and to learn how to domesticate animals (this happened in China ten thousand years ago). Since then, people have broken away from spending all of their energies on escaping natural enemies and getting food from the earth. Now they are able to use more time to think and enjoy 'culture', which carries the same meaning as 'cultivate' in old English. Until now culture was the special contribution of mankind. Because it appeared in the Orient first, we call it 'Oriental civilisation'. It was this old culture that developed in a prehistoric agricultural society (including raising poultry), that enriched the Oriental thought. The central ideas of Oriental thought are as follows: The human species is the product of nature. It comes from earth, and after birth, age, regeneration, illness and death, finally goes back to nature. These were explained by many sorts of religions in the long period of history. Chinese people started to praise Confucianism over two thousand years ago. Therefore, during this long period of time of research and exploration on living things and their environment, Oriental people became skilful in getting limited things from earth. Thus, they tried their best to leave the natural surroundings for later generations. The specialities of the thought of Orient are as follows:

i) The base for building a country is by means of agricultural development. This concept has been deeply accepted by Oriental people since two thousand years ago.

ii) The everyday life of people is filled with many exciting and romantic activities, such as fishing, hunting, farming, writing and reading poetry, playing qin and chess, painting and calligraphy, etc; everywhere is filled with the romantics of rural scenery.

iii) People deeply believe that being content with your lot will make you happy. They also believe in getting nothing unless it really belongs to you, e.g. building homes through thrift and hard work.

The three points above are the common properties in all Oriental countries, especially those in south and east of Asia.

iv) Chinese people have faced brutal, natural and man-made calamities for a long time. So their characteristics are broad-minded, steadfast and preserving. Today's China is still a developing country, and its national area is less than 7% of the whole world total, China possesses one-fifth of the world's total population. (If China and India are considered together, their continent area add up to only 8.4% of the whole world's, but their population adds up to one third of the world's). From this point, we can understand the importance of Oriental thought.

The Inspiration from Terrace Fields

In China, terrace lands have been built on hillsides which angle at more than 30°. People make use of stones and earth on mountain slopes to set up terraces which are almost vertical, and arrange protection from inside, then put fine earth on the surface of the fields. Generally, the height of a terrace is 2 m or so, but if a mountain slope is steeper, the field enclosed by a terrace will be narrower, and tilled land will be relatively less on the level area. If hillsides are selected which are sheltered against the wind and toward sunlight to build up terrace lands, the mountain slopes help to increase intensive farming and comprehensive development. For instance, the planting of apple trees, honeysuckles, peanuts or sweet potatoes as shown in Figure 1 will fully bring out the production of the potential of the earth. This sort of terrace field which is also named the bench terrace is only

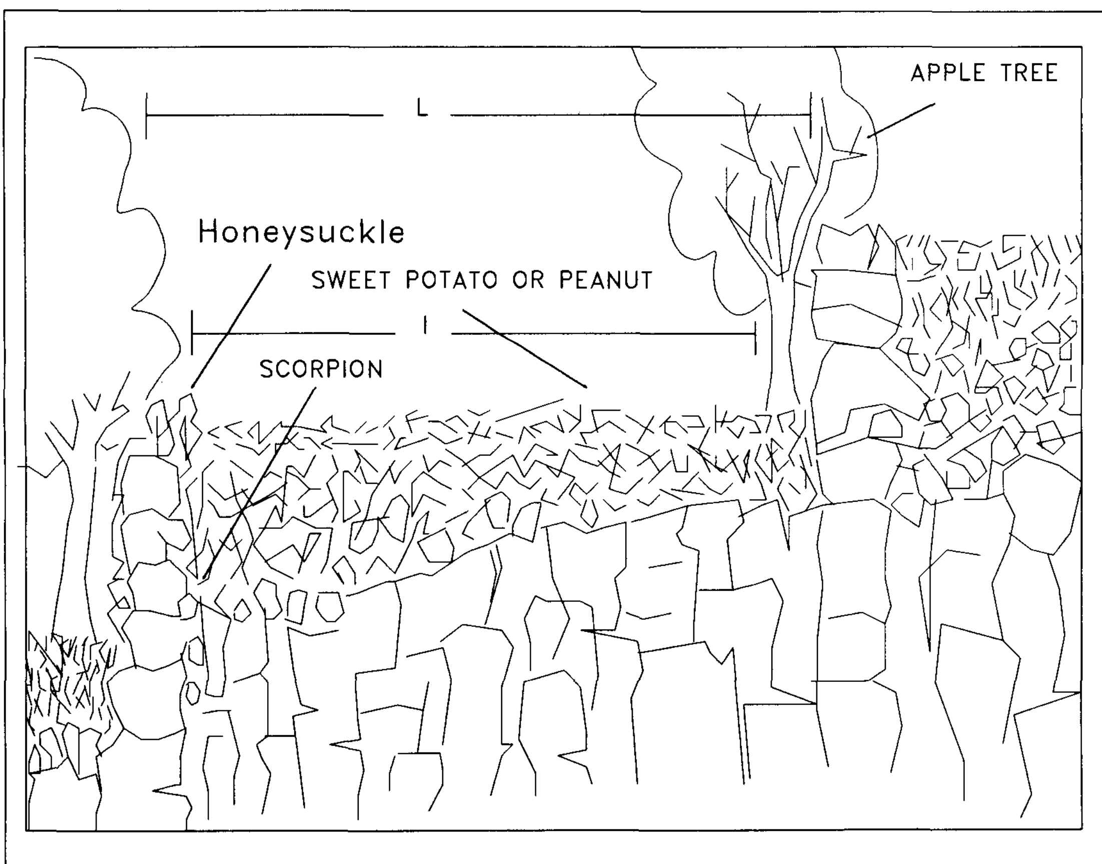

Fig.1 *Terrace and the stereo production system on hill slope*

used in the orient. These traditional terrace fields are built onto mountain slopes by stairs, especially in China and South East Asia. They enlarge the environment by increasing the bearing capacity of the land.

Lopsided Forestry and Forestry Science Development

After the period of the Renaissance, western civilisation attained a new height. The Renaissance brought about a great advance in natural science and applied science, and implemented the development of the Industrial Revolution, with industrial technological development as the core. As the development among science and technology was lopsided, some subjects were in a passive state of development. Such a subject was forestry science.

The vegetation on the land consists of forest and prairie. Forest, with the highest biomass and species diversity, is the most important component of the vegetation. Animals mainly feed on plants directly or indirectly, and people depend on it for their life and livelihood. Without natural vegetation, there would be no life on earth. In fact, the Industrial Revolution was a scientific technological revolution, which composed mainly of inorganic substances. The sources of energy and raw materials needed for industries were natural resources, such as mineral, and biomass resources. Forests provide raw materials for industries and energy resources as well. So with the development of industrial technology, forestry and forestry sciences are regarded as applied sciences, i.e., how to get timber from the natural forests and how to process and use the timber.

Agroforestry to Help Energy Requirements in Countryside

Xiji, with serious water and soil erosion, is a poor county in the Loess Plateau of Northwest China. In 1979, the average annual capitation gain and income were respectively 220 kg and 35 Chines Yuan (RMB). Its population of three hundred thousand needs 257,000,000 kg of fuel. But the supplies of 32,000,000 kg residues of crops, 83,000,000 kg animal excrement, 15,000,000 kg tree leaves and branches, and 1,500,000 kg coal only make a sum of 131,000,000 kg. Another 126,000,000 kg can only be gotten from digging sod, that causes over exploitation of grassland and results in degradation of ecological environment. According to the investigation, one person can dig 15 kg of sod a day that destroys 0.033 ha grassland. To improve the situation, from 1981 to 1986, 43,000 ha trees and 75,000 ha grass were planted. The area of plant cover was 37.2% in 1985. By 1986, a total of 154,000,000 kg firewood from planted trees and grass was provided, that met 84.2% of total firewood demand. With additional coal supply and energy-saving stove technology development, the energy problem in that county was solved.

Soil and Water Conservation in Xiaolong of Guangdong

Lingnan, located in the south tropics of China, with an average annual rainfall above 1,000 mm, is covered with rain forest and monsoon forest but human activities have caused serious degradation of natural environment. Large areas of land started to become desert in 1950s. By 1980, deserted land along the coast in Guangdong was more than 1,000 Km^2. At that time soil was being lost at a rate of 10,000 m^3/Km^2 per year. More and more fine soil with organic matter was washed out. Quartz sand remained in the slopes and gullies. Soil fertility was dropping. Finally the "red desert" was formed.

Since the foundation of the water and soil conservation station in 1957, by combining vegetative measures with engineering measures, more than 2,200 checkdams have been built, and 400 ha of drought-enduring and fast-growing *Eucalyptus* and pine plantations have been established in the "red desert". According to the experimental data, soil losses in *Eucalyptus* forest and pine forest were 50% and 70% less than the control respectively. At the same time, soil water content and organic matter increased by 1% and 0.76-1.13% respectively. But the loss of water and soil in forest land still remained serious. In 1964, by the conservation measure of trees, shrubs and grass in combination, the ecosystem was improved. The data obtained from the investigation in 1982 showed that the number of plant species reached 119, much higher than 51 originally introduced. Over 400 insect species and over 100 species of birds and other animals were found in the newly formed ecosystem. That also showed that the ecosystem has the ability of self-recovery and self-regulation.

In October, 1981, with a rainfall of 120-140 mm, it was found that run off coefficients in the mixed planting system and eucalyptus plantation were 6.6% and 85% respectively. By testing the soil several times during several rainfall periods, the loss of soil in desert land, *Eucalytpus* plantation and mixed planting system were found to be 19,897.5 kg/ha, 5,677.5 kg/ha and 3.2 kg/ha respectively. There is no obvious border in ecosystem. The improved part of an ecosystem will certainly affect the surrounding areas. The surface temperature of the desert land near the part was never 62°C, and the environment conditions of the rice field also improved.

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Light Distribution in Tree Intercropping Area and its Agricultural Value

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ABSTRACT

In this paper, emphasis is laid on the analysis of the daily temporal and spatial variations in the shady area and the shading intensity of a single tree in intercropping area, showing the features of the total relative sunlight distribution in the field of Paulownia. The shading effects and practical agricultural value of three structural patterns of tree rows in tree-crop intercropping is discussed. It is found that Paulownia-crop intercropping has greater potential in agricultural production owing to the small shady stress of Paulownia trees on crops.
Key Words *Illumination; shadow transmissibility; sum of relative direct sunlight; structural pattern*

Introduction

Tree-crop intercropping is a traditional farming system in China and advance in research has shown great potential of this system. Its importance lies in the fact that an improved ecological environment shows considerable benefits to the growth of crops on the farmland by careful selection of tree species and rational cultivation measures. Tree-crop intercropping is a complex community composed of perennial trees and annual herbs. The large crown of the tree produces a striking shade effect. Because the plant height ratio of tree-crop intercropping (from 5 to 15 m) is far greater than that in pure crops (from 1 to 5 m), an entirely new pattern for light utilisation is formed. Though this intercropping system, as a whole, can increase the biological yield per unit area, the tree shade is inhibitory for crop growth. How to reduce this influence is a difficult problem. Based on observational data, analysis has been made of the effect of tree shade in the field during sunny weather, thus revealing the laws of temporal and spatial distribution of the tree shading and the variation in illumination. This study will help to improve the farming techniques in order to bring into full play the productive potential of the tree-crop intercropping.

Research Methods

The Huangheya village in Dezhou City of Shandong province (116°19'E, 37°26'N) with a network of windbreaks was selected as the experimental field. The tree species planted for the windbreak is Chinese white poplar (*Populus tomentosa*), and those for intercropping is *Paulownia*. Intercropping trees run from north to south with a planting spacing of 10 x 50 m. The average height of trees was about 11 m with the stem height under canopy about 2.2 m.

Observations were made twice in 1985, once from April 25 to May 8 and the other from August 12 to 16. Two neighbouring *Paulownia* trees were selected as the samples. First, distinguishable surveying poles were dug around two sample trees in different directions and at different distances. In order to avoid any difficulty in obtaining reliable measurements, short-stalked crops were planted as the under-vegetation. The crops at our two observing times were wheat before heading and peanut at the flowering stage respectively. Observations were made once every one or two hours from sunrise to sunset, including solar elevation, solar azimuth, shadow length and width of trees, and illumination at different points inside and outside the shadow. At the same time the weather conditions were recorded. The instruments used were Olinov all-powerful compass, LH-85 solar altimeter and ZF-2 illuminometer. In addition, the crops grown in large meshes of the network of windbreaks were investigated extensively. Special attention was paid to the differences between the crops growing near the trees of the windbreak and intercropping, thus providing a criterion for the shade intensity of trees.

Results And Discussion

Temporal and Spatial Distribution of Shades of Trees - Locus of Shade Movement During a Day -

The shape, area and location of the canopy shadow vary regularly with the apparent motion of the sun in the sky during the daytime. The daily change of the shadow shape depends on the sun's elevation. Suppose the canopy of a broadleaf tree is an ellipsoid, the canopy shadow will always assume an ellipse varying with the apparent motion of the sun. The change is mainly in the length of the lengthwise semiaxes a'. Thus, the change in the shortwise semiaxes b' is negligible.

Observation shows that, according to the criterion that the outline of the canopy shadow can be distinguished, the shadow length varies approximately from (2a'*4) to 2b' to (2a'*4). At sunrise and sunset, the canopy shadow becomes a dim image and loses its practical value. The scope of the moving shadow in a day can be described as a locus as shown in Fig. 1. It appears as a limited shallow arc belt, whose inner and outer radiance are different varying with the sun's apparent motion that depends on season and latitude. During the growing season, the radiance increases with latitude and the inner radiance is related to the height of the trunk, and the outer to the height of the tree. Thus, the locus of the shadow in a day becomes a belt whose changes are slightly larger at dawn or dusk, and smaller at midday.

Distribution of Shadow Illumination -

The illumination of the canopy shadow is dependent on the shading ability of the tree (canopy density) and the intensity of incident light. Let the transmissibility r denote the light intensity at a point shaded by the tree S to the light intensity in the unshady field. So the shadow transmissibility is r = S/So x 100%. Obviously, besides depending on the character of the canopy and the leaf density, the transmissibility, according to Beer's Law, has to do with the variable track of the incident light transmitting through the canopy. Fig. 2 shows two

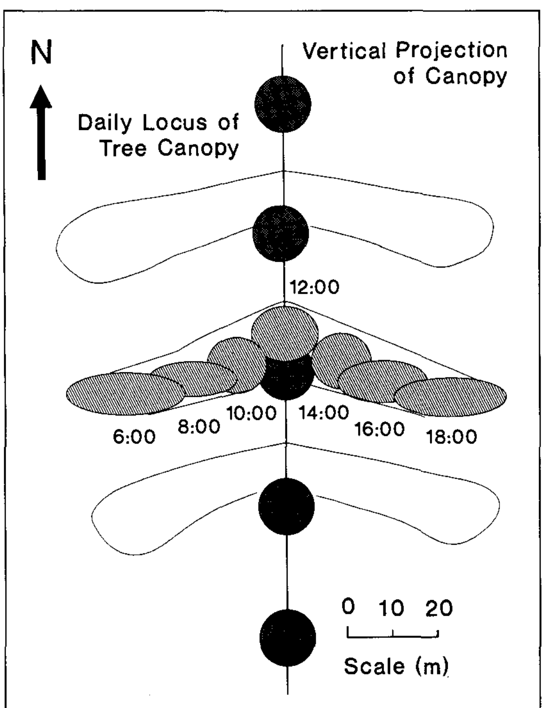

Fig 1. Change in light distribution effected by inter cropped trees

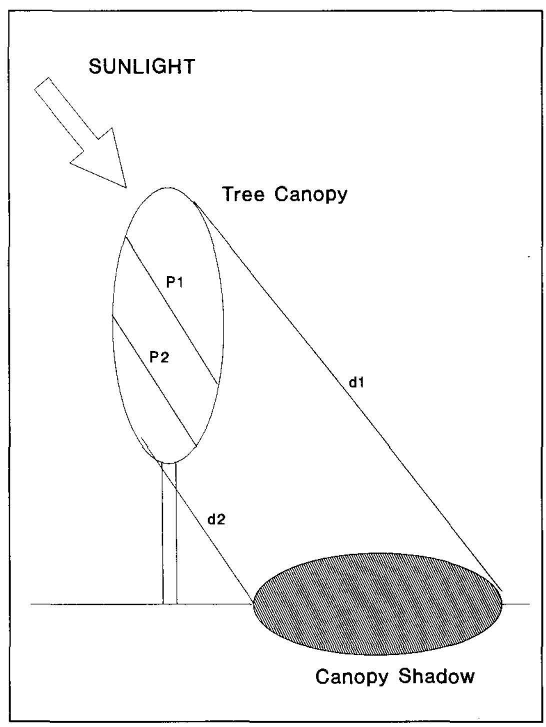

Fig 2. Tree canopy and its shadow

factors that influence light intensity in the shadow:

1) Higher the sun's elevation, the longer the track of the light transmitting through the canopy, and smaller the transmissibility, i.e., the darker the shadow becomes.
2) Greater the distance from the canopy's back to the ground surface, the greater influence the scattering radiation will have on the light intensity, so that the light intensity at the same point will increase. On the shadow transmissibility, two characters have been developed. For light distribution, the distant point of the tree will always light more than a near one, as seen in Table 1. On the other hand of daily change, as shown in Fig. 3, the r was the lowest at midday and the largest at morning or dusk, i.e., the gradient distribution of r was larger at midday than at morning or dusk. It is well known that the carbohydrate produced at midday under the normal light condition should be more in a day. In spite of the shadow, illumination is lighter at midday compared to other times during the day (Fig. 4). The shadow stress influenced the crop growth is worse at midday than at other times.

Total Distribution of Direct Sunlight on the Ground Surface Around the Tree -

Neither shady area nor shade light intensity in tree-crop intercropping can fully characterise the photosynthetic environment of crops. It is best to account the daily sum of shady area and shade light intensity. Let the sum hourly variations during a day in illumination at a given point in the field be the sum of the direct sunlight (Ri) at the same point that day. And the ratio of Ri to the direct sunlight on the unshaded ground surface at the same time (Ro) is defined as the sum of relative direct sunlight (KST). Then the KST at each point is calculated and compared so that we may know the distribution of the total shading in the field during the day. It is quite evident that the shadow in its daily locus has a regular change in area and location depending on the sun's apparent motion. The KSTs in different directions and at different distances around the trees are very variable. As seen in Fig. 5, the changes in the KST on both the east and west sides of the tree are approximately the same, and the value on the north side is smallest while the value on the south side is considerably greater. This phenomenon is obvious particularly in the area where the canopy has vertical projection. As a result, the crops on the north side of the tree in tree-crop intercropping grow the worst. As far as the yields around the tree, we may have the low yield region, the normal yield region and the high yield region, which are distributed in a ring with different widths around the tree.

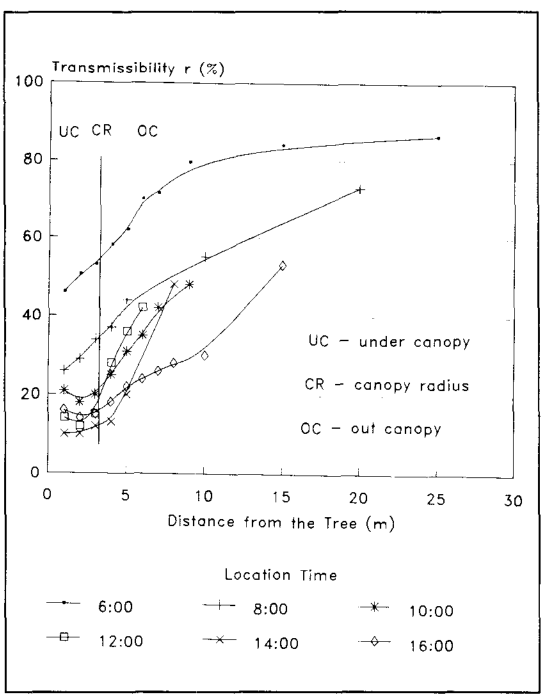

Fig 3. Light intensity at different distances from tree trunk

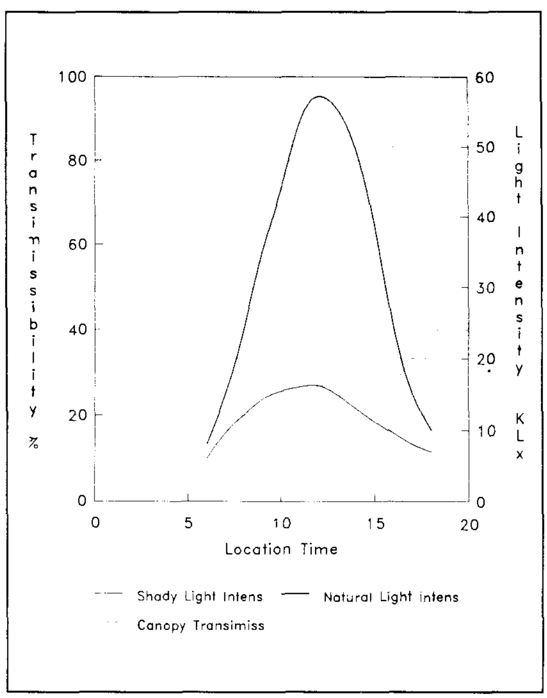

Fig 4. Relative light intensity and its percentage transmission at different times

Effects of the Tree Rows in Tree-crop Intercropping on the Illumination in the Field -

Depending on the distances between two plants and two rows in tree-crop intercropping, structures of the tree rows may be divided into three patterns: Sparse structure pattern is characterised by great plant spacing and wide row spacing. Take *Paulownia*-crop intercropping as an example - here the width of the canopy is smaller than the plant spacing. The tree allows sunlight to penetrate through the neighbouring canopies in the same row in which there is no overlap. On the other hand, if the row spacing is greater than the longest shadow at dawn or dusk, shadows between two rows cannot overlap either. For this reason, shading division of the tree community in a field depends only on the summation of all the shaded areas around the tree. The total shaded area of the tree community accounts for only a small proportion in the field. The shaded and unshaded areas are distributed in a scattering pattern, as shown in Fig. 1. Thus the structure of tree rows has very slight influence on the growth of crop plants.

Hedgerow structure patterns are characterised by small plant spacings and wide row spacing with canopies linked to each other in the row, forming a green hedgerow. As canopies in the row are closed, the daily locus of tree shadows has nothing to do with the shape of each canopy but depends on the height and scattering of the canopy in the hedgerow. Studies have shown that for a windbreak strip, namely, a hedgerow, the primary factors influencing the distribution of tree shadows are the shadow width (L) and the distance from the observing point to the tree row (X). Let H denote the mean height of trees, ho the sun's elevation, A the sun's azimuth (south being 0^o, clockwise readings positive, and the counter clockwise readings negative) and B the azimuth of the tree row, then

$$L = -H \times Ctg(ho) \times Cos\,(A-B)$$

where (A-B) is limited in quadrant I or IV. Consequently, an equation for the transmissitive area of the tree row can be fitted as follows:

$$r = a_0 + A_1(\frac{X}{H}) - a_2(\frac{X}{H})^2 + a_3(\frac{X}{H})^3$$
$$- a_4(\frac{L}{H}) + A_5(\frac{L}{H})^3 - a_6(\frac{L}{H})^4 + a_7(\frac{L}{H})^5$$

where a_i represents parameters, i = 0, 1, 2, ... which varies with the tree species and weather pattern. The shaded area conforms to the following principles:

1) The light intensity at a point far from the tree is successively greater than that of a closer one.
2) Transmissibility is the smallest at noon, increasing gradually until it is the greatest at dawn and dusk. It is seen from Fig. 6 that KST distribu-

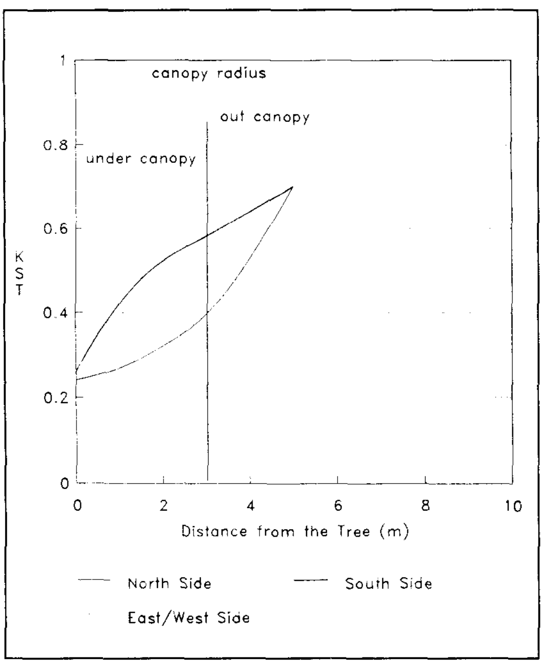

Fig 5. Radius of tree Canopy in relation to tree trunk

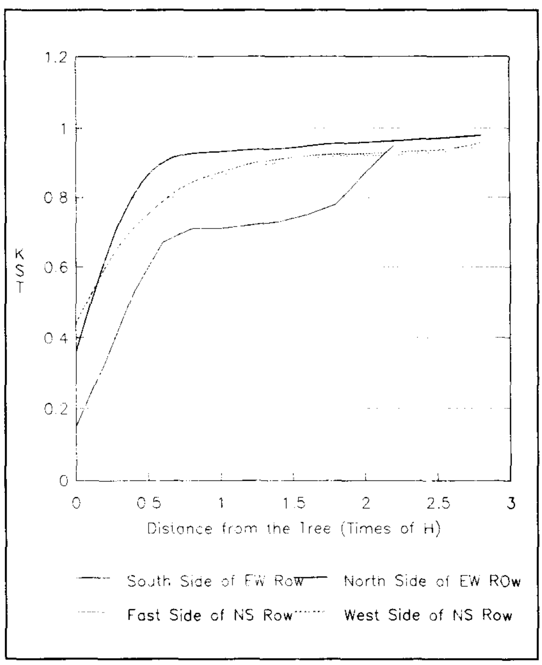

Fig. 6. Relative direct sunlight (KST) at different distances from tree trunk

tion near the tree row is in a symmetrical east-west orientation. However, due to some overlapping of the hedgerow shadows between neighbouring canopies, the transmissibility is smaller than that in the sparse pattern. For this reason, tall trees are not suitable in the hedge row intercropping pattern. It is desirable to plant small and short tree species in the intercropping, Chinese ash-crop intercropping for example.

Compact structural patterns are for small plant spacings and narrow row spacings. In this case, sunlight in the field not only depends on the overlapping of shadows between neighbouring trees in the same row, but when sunlight shines obliquely, it will produce overlapping shadows between neighbouring rows and the probability of the ground surface receiving direct sunlight decreases with the increase of sunlight penetrating the canopy (n). The transmissibility of sunlight on reaching the ground depends on the sum of sunlight passages through the n layers of canopies. In order to determine the component (F_β) of direct sunlight reaching the ground in this intercropping, the equation by Mann *et al.* (1980) may be used as follows:

$$F_\beta = \mu_n \exp(-\delta \cdot \lambda_{n,1}) + (1-\mu_n) \exp(-\delta \cdot \lambda_{n,2})$$

This equation is derived from the probability that a randomly selected point on the ground is shaded by the tree canopy. In the equation n is the number of the tree rows penetrated through by the direct sunlight reaching the ground between the rows. As a rule, n is seldom greater than 3 in the effective period from one hour after sunrise to one hour before sunset. The proportion of the total field area in the vertical projection of tree rows is represented by u_n, while ($1 - u_n$) is the proportion of the field area stripe uncovered by tree rows.

$$\delta = 1 - \exp\left(\frac{-L_\beta}{\delta . A_\beta}\right)$$

$$\lambda_{n,1} = \delta \cdot A_\beta \cdot \frac{\varphi_n}{\mu_n}$$

$$\lambda_{n,2} = \delta \cdot A_\beta \cdot \frac{1-\varphi_n}{1-\mu_n}$$

In addition, L_β is the leaf area index of the canopy in the vertically projected ground area, δ the planting density of trees, A the shady area of the canopy that varies with the sun's elevation β, q is the ratio of the width of a canopy projection measured vertically on the ground to the width between rows without projection, and ϕ_n is the component of the projection of a single canopy between rows.

$$\phi_n = \begin{cases} 0 \\ \frac{2}{\pi}\sum_{i=1}^{n-1} di \end{cases} \qquad n = 1, \; n > 1$$

$$d_i = \arcsin\lambda(q,i) + \lambda(q,i)\sqrt{1-\lambda^2(q,i)}$$

$$\lambda(q,i) = \frac{2i}{q} - 1$$

In the compact pattern of tree-crop intercropping the component shine on the ground is small, and the shading is dark. Therefore, the powerful shading effect of this structural pattern is not favourable to the ground of most crops. However, if we select trees that require weak sunlight and high humidity as the "shady trees" for the underlying vegetation, the compact pattern structure shows some advantages for raising the yield and improving the quality of crops. For this reason, some pairs in the intercropping, for instance, *Paulownia*-tea tree and rubber tree; tea or some medicinal plants have produced good results.

Tree-crop Intercropping and Selection of Crop Species -

The economic benefits obtained from the illumination distribution feature in tree-crop intercropping depends not only on the planting density of trees but also on the tree and crop species. Obviously, canopies with small bulk and great transmissibility have weak shading effects. Thus *Paulownia* with sparse canopy has outstanding adaptability. As seen in Table 2, measurement under the same condition shows that shadow transmissibilities of willow and Chinese white poplar are 21% and 36% lower than that of *Paulownia* respectively. This is the biological basis for the development of large-scale *Paulownia*-crop intercropping. ,

It must be pointed out that the yield of crops is also related to their reaction to shading. Comparison has been made of the plant height and growth rate between many crops growing luxuriantly in the intercropping field. It is found that crops sensitive to shading are sunflower, maize, millet, cotton, soybean, wheat, etc. These crops vary greatly in growth with the distance from

Table 1. Shadow distribution at different times at different distances from tree trunk

Local Time	Shadow Length (m)		Shadow Transmissibility (%)		
	trunk	canopy	near point	mid point	distant point
6:00	8.0	39.0	75	88	91
8:00	5.0	13.0	47	57	73
9:00	3.0	10.0	23	50	73
10:00	1.8	7.2	17	36	50
11:00	0.8	6.0	15	27	42
12:00	0.5	5.5	15	17	44

(Observed on August 5, 1985, tree height 11.3 m)

Table 2. Comparison of shade condition caused by different tree species

Tree Species	Tree Height (m)	Shade Condition					Mean Transmissibility
		LP		DP		ISa (KLx)	
		AR	LI	AR	LI		
Paulownia	11	20%	27.0	80%	13.0	15.8	53%
Willow	9	10%	17.0	90%	12.0	12.5	42%
Chinese Poplar	15	5%	15.4	95%	9.8	10.1	34%

LP=light point, DP=dark point, AR=area ratio, LI=light intensity, Isa=illumination sum at all shadow; Observation time: 9:00-9:30, So=30.0 k Lx)

Table 3. Rows of maize plants affected by shade condition

Shade Inhibition	Width of growing area of maize (H)	
	Paulownia	poplar
heavy	0	0 - 0.20
middle	0 - 0.18	0.21 - 0.40
weak	0.19 - 0.36	0.41 - 0.80

H is tree height. Paulownia is intercropped with crop. Chinese white poplar is planted in the windbreak row

the tree. Crops less sensitive to shading are peanut, sesame, sweet potato, etc., the growth of these crops seems to be not closely related to the distance from the tree. Whatever crop is paired with *Paulownia* in intercropping, its growth is not so heavily inhibited as under the windbreak row. Table 3 shows the growth of maize is not so heavily inhibited when intercropped with *Paulownia* as with non-*Paulownia*. It is also shown that poor maize grown under *Paulownia* shadow is much less inhibited than in the shade by other trees.

Conclusion

The shadow of trees has a decisive effect on the illumination distribution in the field of tree-crop intercropping. This is so-called shade stress. In general, this effect is harmful to the field crop. The illumination distribution influences the daily locus of shade images of the tree canopy, but shadow varies with the shape, area, daily locus and transmissibility of the canopy, and can be defined as the sum of relative sunlight at each point on the ground surface.

Generally, according to structure, tree rows in the tree-crop intercropping may be classified into three patterns, i.e., sparse, hedgerow and compact structural patterns. The shade theories and calculation methods are different, hence they have different practical value in agricultural production and have to be applied in different ways.

The feasibility of tree-crop intercropping is closely related to the species of the tree and crop as well as the cultivation methods of trees. With its structure *Paulownia*-crop intercropping can decrease shade stress favourable to high yield of both trees and crops. However, cultivation techniques should be improved in *Paulownia*-crop intercropping to reduce the harmful effects of shading.

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II. AGROFORESTRY SYSTEMS IN WARM TEMPERATE ZONE

Forest Network and Intercropping in North China Plain (Shandong)

Paulownia (Paulownia elongate) - Wheat Intercropping (Yanzhou, Shandong)

Chinese Date (Ziziphus jujuba) - Peanut Intercropping

Shrubby Ash (Fraxinus chinensis) - Peanut Intercropping

Forestry Development in Plain Agricultural Area

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ABSTRACT

North China plain covers an extensive area, part of it used for agriculture. Of late, agroforestry methods have been introduced in this region to increase crop and wood production. Different aspects of development are outlined in this paper.

Introduction

Plain forestry is an industry of planting, growing and protecting of plain agricultural areas to obtain forest products and improve the ecological environment. Through long-term practice and acquisition of forestry experiences, plain afforestation has come to be a part of the forestry production system and has played an essential role in developing the rural economy in China. As a result of the establishment of farmland shelter forest systems, the ecological environment for agricultural production has improved with a steady increase in agricultural output. In particular, the increase in timber supply has considerably relieved the shortage of wood for fuel. The development of the timber-processing industry has helped to re-adjust rural industrial structures and brought about numerous economic and social benefits. At present, in counties where much good work has been done in plain afforestation, forestry industry has improved in terms of production, circulation and consumption of various agroforestry products. Adequate references are made at the end to the concerned literature.

The Past and Present Situation of Plain Forestry Development

North China Plain covers a total area of 3,228 million ha constituting one of China's most vital plain regions for agricultural production. And this region in particular shows rapid development of plain afforestation. Its development has gone through four stages:

First stage: This stage lasted from the early 1950s (closely after the founding of the People's Republic of China) to early 1960s; the major achievement during this period consisted of creating windbreaks and sandfixation forests. After 1956 afforestation programme started in main agricultural areas by planting trees on "four sides"; namely, the sides of houses, villages, roads and various waterways.

Second stage: Combining with the capital construction on farm-land, the "four sides" tree-planting branched out on the sides of farmlands. Gullies, woods, ditches and roads were integratively planned and managed. Thereby a new pattern of farmland shelter forest came into being.

Third stage: On the basis of perfecting farmland forest networks there began a drive for intercropping agricultural crops with trees, and fast-growing woodlot establishments. It was in large measure a system of combining networks, belts and tracts for the purposes of shelter forest and timber production.

Fourth stage: Over the last few years there emerged a new breakthrough in plain forestry. Various regions began to link forestry development with re-adjustment of rural industrial structure and development of rural economy. The comprehensive system of shelter forest and timber production which includes intercropping on farmlands, forest networks, high-yield woodlot, tree-planting around villages and so on was transformed into yet a newer system of multi-layer structure and multipurpose agroforestry. At the same time, through the development of wood processing and utilisation, an integral whole production system of forestry, industry and trade has been forming.

The development of plain forestry proceeds

Table 1. Forest coverage and stock in selected provinces.

	Hebei	Henan	Shandong	Shanxi	Anhui	Jiangsu
Coverage (%)	9.7	1.1	7.1	15.0	13.9	8.0
Stock (m/m^3)	9.00	31.05	35.05	17.0	19.41	25.00

along the lines of the laws of nature and economic principles. It starts off by learning about the workings of nature and the step by step transforming of nature. The management objective has developed from the original single protective function into the double objective of protection and economic benefits. The management pattern has also changed from the state and collective operation to household avocation. The content of management is now no longer purely forestry management, but an integrated forestry production system of cultivating, cutting, processing and utilisation, and the planting pattern has shifted from monoculture of forest tree species to mixed planting and multilayer structure.

At present, plain forestry mainly ranges over farmland forestry networks, intercropping of crops with trees, and the planting of trees around villages and fast-growing woodlot establishments. The 1987 statistical data show that in 387 counties across the provinces of Hebei, Shandong, Henan, Anhui, Shanxi and Jiangsu, numerous farmland forest networks have been built occupying a total of 11.20 million ha accounting for 48.5% of the said provinces' farmland in total. The acreage taken up by intercropping of crops with *Paulownia* trees amounts to 3.26 million ha, i.e., 59.1% of the provinces' arable lands. The figures in Table 1 show the numerical aspects of the forest coverage and stock in the above-mentioned six provinces.

The position and the role of plain forestry in forestry production and plain agriculture economy in China can be summarised as follows:

1) Plain forestry has been an important component in forestry production systems. It not only contributes to the increase in forest coverage, but with the increase in timber production. It also helps to alleviate the long-existing situation of shortage of timber supply in the plain area, thereby creating a good condition for the rehabilitation of old forest areas in North and South China.
2) Plain forestry development is an important method to improve the economic situation of the areas through rational development of land use systems and reasonable utilisation of natural resources.
3) Improved ecological environmental conditions through integrated farm forestry development guaranteed the stable development of agricultural production, promoted the readjustment of rural industry, and strengthened the rural economic strength.

The Characteristics of the Plain Forestry Production

Compared to the forestry development in the mountainous and hilly area, plain forestry has its own characteristics, they are:

Unified Planning and Individual Household Management -

Farmland accounts for 65% of the total land resources in plain agricultural areas. The share of exclusive forestry land is only 5%. Under that situation, people mainly use the open spaces beside roads, river banks, ditches, around villages and towns as well as part of the farmland to interplant crops and trees in addition to using the 5% of land. As forest land and resources are relatively scattered, the management system of land resources involves agriculture, water conservancy, traffic, village and town construction, etc. So unified planning seems even more important. Anhui province has adopted a measure to integrate the ditch, road and forest, thus turning the "four sides" green; in other words, it planned the construction of water conservancy, road and forest integrally thereby achieving the planting near the ditch, road and forest. This type of multi-departmental approach in developing plain forestry is a pioneering work in this area.

Plain forestry takes individual household management as the dominant operating form. Before the reform of rural economic system, forestry production was generally undertaken by commune and brigade run forestry farms, and was mainly managed collectively. After adopting the joint-production land contract responsibility system in agricultural production, the right of land management has been returned to the farmers and various productive elements are disposed and composed according to the demands of family management. Thus the farming households have become relatively independent economic entities. Adopting individual household management as the main form is therefore an effective management form to guarantee the unity of the right, responsibility and benefit of farmers in operating forestry. As to the large forest belts along the main roads, rivers and ditches, the form of management varies with every locality. Most localities divide the forest belts into sectors which are contracted to the separate villages and then they contract the trees to the individual households for care and management. The returns are distributed in proportion. This is useful in mobilising the enthusiasm of thousands of households.

Agroforestry -

In agroforestry, forestry trees (including shrubs) and crops are grown on the same unit of land according to certain compositions to form an organic combined cultivation system.

Historically, Shangqiu Prefecture of Henan Province suffered serious damages by wind and sand. To resist the attack of wind and sand to agriculture, 94% of the farmland has been surrounded by forest networks. Various intercropping systems such as crops and *Paulownia*, crops and fruit trees, crops and shrubs, have been developed in these areas, that result in 97.6% of the total arable land intercropped. From the management of agroforestry, the economic situation of this prefecture has improved. Compared to 1978, the output of grain and oil, and per capita income increased by 62%, 275% and 191% respectively in 1985.

Guaranteeing grain production is a basic policy of China's agricultural development. Whether the rapid development of plain forestry can affect the grain production is a matter of interest to every one and a key problem concerning whether plain forestry can develop regularly. Taking Fuyang Prefecture in North Huai Plain, Minquan County in Shangqiu Prefecture, and Fugou County in Zhoukou Prefecture of Henan Province as examples: In these three prefectures or counties plain forestry was developed rapidly with large acreages of forested land. The data listed in Table 2 shows grain production on this forested land. From Table 2 it can also be seen that the annual grain output increased steadily from 1980 (except for Minquan County where the grain output decreased slightly in 1986 because of severe drought). Compared with that of 1980, the output increased by 84.89%, 51.98% and 67.61% respectively in 1986. Within the same period, the increase in the whole county was only 22%, averaging a mere increase of 2.9% annually. The increase of grain output is a concern of scientific technological advancement, the application of improved strains, the widespread application of chemical fertilisers and pesticides, and the protecting benefits of forests should not be under-estimated.

Intensive Management and Short Rotation Forestry -

In plain regions greater stress is laid to the intensive forest management mainly concerning the following three respects:

1) Species selection - constantly substituting fast-growing tree species for old ones, such as using Lombardy Poplar to replace Balsam Poplar, and Henan No. 1 *Paulownia* hybrid to replace Lankao *Paulownia*.
2) Improvement of the quality of planting materials - use of big seedling for planting, and shortening the years of growth into useful timber.
3) Intensive management - intercropping, protection and fertilisation.

Investigation in Zhoukou Prefecture shows that the DBH (diameter at breast height) of 3-year *Paulownia* intercropped with crops reached 12-14 cm, which generally can grow into purlin timber in five years. The DBH of 22-year old Lankao *Paulownia* is 41.2 cm. With the fast-growing forest tree species, the rotation of timber plantation is ten years, and that for purlin timber is only five years. The growth cycle is shortened by one or two times compared with the Chinese Fir forest in South China. It is also favourable to the circulation of funds and maintaining the enthusiasm of farmers for production.

Village Forestry - A Pioneering Work in Plain Forestry -

Villages and towns usually account for 10-15% of the total land area in plain agricultural regions on which along with the land occupied by houses and buildings, there is quite a lot of spare land available. Using this spare land around the villages for tree planting is an unprecedented undertaking to develop forestry in plain agricultural regions. The forest around villages has become a main component of plain forestry as well as a productive base of timber in North Huai Plain. Developing forestry around villages has four advantages:

1) It does not occupy any basic farmland, yet it

Table 2. Grain output in selected counties/prefectures (1980-1986). (Unit: 100 million kg)

Prefecture or County	1980	1981	1982	1983	1984	1985	1986	Annual Increase
Fuyang	25.25	30.85	39.58	30.51	40.90	38.04	49.69	9.17%
Minquan	1.37	1.53	1.63	2.44	2.26	2.55	2.11	6.15%
Fugou	-	-	-	-	-	-	2.95	7.65%

improves land productivity and economic benefits.

2) It facilitates the farmers' intensive management during their spare time.
3) It allows for greater freedom in management: The farm households can arrange operation and felling according to their own needs.
4) After the construction of the forest around villages, forest coverage can reach 60-70%, beautifying the environment.

Rapid Development of Forestry Economy -

Rapid Increase of Forest Resources through Cultivation - Since the start of the reform of rural economic system, forestry production has developed with unprecedented speed in North and Central China where forests were very deficient before. In Henan Province, the total forest volume stock accounts declined from 76.20 million m^3 in 1976 to 61.66 million m^3 in 1986, a decrease of 19.1%. But in the plain areas, the forest stock accounts increased from 27.07 million m^3 to 31.05 million m^3 in the same period, that is an increase of 14.7%. The forest coverage in the plain area rose from 5.5% in 1976 to 12.1% in 1986, an increase of 6.6%.

Constant Increase of Timber Output and Forestry Output Value - For a long time the timber needed in North and Central China depended entirely on unified state allocation. With the upsurge of plain forestry, the extreme shortage of timber was primarily relieved. In Fuyang Prefecture, the annual output of forest since the 1980s was 4.9 times the figure of state allocations in the 1970s, and the forestry output value rose 2.7 times between 1981 and 1986.

Fast Development of Forest Industries - The timber market in the plain regions, which takes fair trade as its main form, was opened early. Thanks to the smooth circulation links, the timber processing industry has developed rapidly. In Heze Prefecture of Shandong Province, there are more than 320 *Paulownia* timber processing plants which process 57,000 m^3 of timber annually. Plain forestry has now begun to develop toward the integration of producing, processing and marketing.

The Reason for the Rapid Forestry Development

Before 1980s, forestry development mainly depended on the government at different levels to take various administrative measures and carry on mass movements. Since 1980s, relying primarily on policy, and then on scientific method has become the voluntary action of the growers.

Demand for Forest Products

Although there are a number of advantages in developing agriculture in the plain agricultural regions, the farmland ecological system which lacks the protection of the forest, is very fragile in structure. Hence, various natural calamities can directly harm the steady development of agricultural production, e.g. the dry and hot winds of North China which can reduce the wheat crop yield by 10-12%. Setting up an integrated shelter-forest system composed mainly of forest networks will effectively enhance the ability to cope with natural calamities. In this respect, the farmers have abundant knowledge. In plain areas, trees were scarce and farmers suffered from lack of timber and fuelwood for a long time. And today, the demand is even greater. At the same time, as forestry brings more economic benefits to farmers than does agriculture, developing forestry in plain areas has certain practical economic value.

More Freedom in Management and Marketing -

Whether the initiatives for forestry production can become effective also depends on other conditions. After 1987, with the reform of the rural economic system, land was contracted to individual households for management, and the ownership of land and the right to operate have been separated, thus unifying the responsibilities, rights and benefits of the farmers in undertaking agricultural production. The reform of agricultural production created simultaneous reforms for forestry production in ways suitable for the agricultural household contract responsibility system linking output. This policy clearly stipulated that "the trees follow the land, whoever plants them owns them and the management is also up to him". In this way, the ownership and distribution of forest property are made clear, and the responsibilities, rights and benefits of the farmers for forest operation truly integrated. As a result, the enthusiasm of thousands of households for developing forest is mobilised.

Opening of Timber Markets and a Negotiated Price Policy -

The opening of timber markets and a negotiated price policy dispelled the farmers' fear for the source of timber production, unified social demands, and adequate economic benefits for the farmers through the market mechanism. In the timber market, in addition to fair trade, specialised timber stations and stores have also been set up one after another. The opening of the timber market not only impelled forest commodity production to develop, but also improved the farmers' concept of commodity economy.

In plain area, not only is the price of timber rational, but the burden of tax is light. When farmers sell their timber, they only have to pay 3% of the total trading price towards the market management tax, and all other taxes are borne by the buyers. But in collective forest areas in Southern China, the farmers' burden of taxes are 27%. In the plain area, thanks to the light taxation and open price, farmers can gain reasonable economic remunerations from practising forestry. This is advantageous in accumulating funds and expanding reproduction, and it is one of the fundamental reasons why plain forestry can develop so rapidly.

Self-reliance and Short Productive Circulation -

As a result of the lengthy productive period and shortage of funds in forestry production, the development of forestry in China has long been restricted. How to raise funds, shorten productive circulation, accelerate capita cycle and increase economic benefits, these are vital factors for the development of plain forestry. The achievements made in plain forestry depended mainly on self-reliance. In Fuyang Prefecture, Anhui Province, the Provincial Forestry Bureau invested only 15 Chinese Yuan (RMB) per ha annually in 1986. But in Taihe County of the same prefecture, funds raised by farmers accounted for 95% of the total investments, and in Bozhou the figure was 71.74%. Of course, while relying on self-raised funds we should also consider the farmers' economic bearing abilities. From the examples of Taihe and Bozhou we see that in the former the forestry expenditure (not including labour force) is 2.66 Chinese Yuan (RMB) per capita annually, and in Bozhou city it is 1.3 Chinese Yuan (RMB). Their forestry expenditures are less than 1% of their annual per capita income. Spending 1% of the total income on reproduction is acceptable to the farmers, since it will not affect their basic living standard. In addition, to analyse the farmers' psychology of undertaking forestry, farmers are eager to become rich and they desire rapid returns and high benefits in every trade they practise. Therefore, adopting intensive management in forest production, selecting improved fast-growing trees, and practising short rotation, are the characteristics for a successful outcome in plain forestry.

Comments on Plain Forestry Development

The development of plain forestry in the future must focus on coordination of relationship between agriculture and forestry, developing the effective forest management techniques and improving the utilisation of forest resources. In this way productive forces can be developed and improved. To develop forestry in a plain agricultural area there must be assurance that there will be a stable increase in grain production. Thus the operating objective of plain forestry is to construct a good base for agricultural production, thereby combining the ecological with economic benefits, and the forestry production to improve the rural economy. To meet this objective, plain forestry development should:

1) Extensively use spare lands beside roads, rivers and ditches as well as the non-arable farmland for planting trees, shrubs and grasses, thus formulating an integrated shelter-forest system for both the ecological and economic benefits.
2) Employ improved techniques of agroforestry such as intercropping, alley cropping, etc. for full utilisation of natural resources.
3) Establish woodlots on the non-arable land around villages mainly for supply of timber

products to save land for agricultural production, especially for grain production.

4) Develop timber production as a self-sufficient commodity, and scale of timber production should be based on the demands of the local market.

Application of New Technologies and Intensive Management -

Due to restriction of land resources, the development of plain forestry should pay attention to improve the management systems and apply new technologies including use of fast-growing species, improved propagation materials, rational planting with good spacing, species combination, and structure, etc. In this way, higher output can be obtained from limited land.

Open the Channels of Timber Utilisation and Improve the Structure of Products -

At present, the utilisation of timber in plain areas has not been brought to the level of industrial production. Timber is mainly used to build houses and make low grade furniture. Future utilisation of timber should extricate itself from the low layer pattern of taking the log, primary products and low grade products as the main products. So we should actively open the channels of timber utilisation, improve the structure of products and practise oriented cultivation, to meet the demands of timber industry.

Improve Circulation Link and Strengthen Market Management -

In addition to fair trade, there are various other ways that can be taken, such as setting up a specialised timber market, timber store, purchasing, marketing for the farmers. The trade should be convenient both for the buyer and the seller. The management of the timber market must be strengthened to prevent stealing, felling and denudation, as well as evading taxes. The timber market and industry on the whole can be managed on a cooperative basis. Every person who is engaged in selling timber, products, mid-products should have a licence issued by the forestry and business departments.

Set up the Perfect Service System -

To improve the development of forestry production further, we should pay attention to set up and perfect the service system. The context and character of service should be shifted from the unpaid service of pure silvicultural technical direction to the paid service of overall integrated management. Most importantly, the service organisations in the county and village should be perfected. The state should allocate some funds to help the running of service organisations which will gradually realise the self-accumulation of funds, and become independent economic entities.

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Evaluation and Model Optimisation of Paulownia Intercropping System - A Project Summary Report

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ABSTRACT

The total area of Paulownia-crop intercropping (PCI) has reached 1,800,000 ha in China. A research project supported by the International Development Research Center of Canada was set up in 1983 with the objectives of comprehensive evaluation and model optimisation of PCI system. This paper summarises the main research findings of the project:

1)Paulownia has the characteristics of fast-growing, deep root distribution, sparse crown structure, leaves developing comparatively later and falling comparatively early, multipurpose with high economic values. It is a good species for planting in agroforestry systems.

2)The comprehensive evaluations of ecological effects (microclimate, solar radiation, energy balance and water utilisation, soil features and nutrient utilisation), biological effects (animal and microbial communities in the PCI system, growth, development and physiological changes of the intercropped crops and their quality and yield), economic effects (cost/benefit analysis of different planting patterns) and social effects of the PCI show that it is an efficient multiple function farming system suitable for development in this area.

3)Through the application of mathematical models for different PCI systems, the optimal level was reached based on scientific basis which helps in further development of the PCI systems.

Introduction

Paulownia-crop intercropping (PCI) system, a new farming system with high productivity, has been extended on a large scale in the Huang-Huai-Hai Agricultural Plain of China. This new farming system is widely accepted by the local farmers and highly praised by the scientists both at home and abroad. How to evaluate the synthetic effects of the farming system remained a question, particularly for the decision-making organisations. A systematic research plan was worked out in 1973 for in-depth research on PCI so as to provide scientific knowledge for the decision makers and local farmers. This research plan was divided into three phases: (1) It was the beginning of the PCI extension period from 1973 to 1976. The research work emphasised on evaluating the successful PCI systems that were already established in the 1960s to draw proper conclusions and to help the decision makers with basic information to further support the development of PCI. (2) From 1976 to 1978, the research on the cultural techniques and primarily on the multiple effects of the new farming system was carried out to yield the findings that had high values to improve the production. The research findings were highly complimented by the National Scientific Conference in 1978. In the first two phases, it was not possible to investigate the fixed sites due to unavailable data, and it was very difficult to explore the synthetic effects of intercropping systems in multiple dimensions, more so to gain the valuable data for model optimisation. (3) The research work received importance from 1983

Table 1. Nutrient contents of Paulownia foliage in different seasons

Item	P. elongata			P. tomentosa		P. fotunei		P. catalpifolia		Paulownia elongata
	June	August	November*	August	November*	August	November*	August	November*	
Crude Fat	8.7	6.69	7.88	7.88	9.6	6.67	7.98	5.84	8.51	2.67
Crude protein	8.85	15.79	16.02	17.86	13.54	12.72	18.6	16.58	16.43	27.68
Total Carbo-hydrate	-	7.47	9.44	6.38	9.53	6.85	8.10	5.29	6.14	-

**fallen leaves*

and was listed as a national priority research project and obtained support from the International Development Research Center (IDRC) of Canada. A *Paulownia* research station was established in Danshan County of Anhui Province in early 1983. The experimental plantations were installed in the station for synthetic research. Simultaneously, demonstration plantations of the PCI were also established in Minquan County and Luyi County of Henan Province. Systematic studies on the ecological, biological, social and socio-economic effects of the PCI system were started with the aim of providing scientific bases for comprehensive evaluation and model optimisation of the PCI. The research findings of the last seven years is summarised in this paper.

Materials and Methods

Experimental Design and Data Collection -

An experimental plantation was established in Danshan County, Anhui Province. Randomised block design was employed in the study. Five tree planting spacings (5 x 6, 5 x 10, 5 x 20, 5 x 40 and 5 x 650 m) were used as the treatments with three replications. Each block was 760 (EW) x 120 (SN) m^2 in size and between the blocks it was an open field (150 m in width). Control plots (no trees) were in the open field outside the tree planting area. The total area of the experimental site was 21 ha. Three main crop species of Northern China, i.e., wheat, maize and cotton, were selected for intercropping. The area of intercropping plot was 0.2 ha each.

In 1982, a 20 ha demonstration trial with six tree planting spacings (5 x 6, 5 x 10, 5 x 30, 5 x 40 and 5 x 50 m) was conducted in Teiqing Xiang, Luyi County of Henan Province. Eight-four ha of the same type of trials were also established in Minquan County of Henan Province and Danshan County of Anhui Province. Fixed sample plots were also selected in PCI models with different tree planting spacings in Yanzhou of Shandong Province. For some research areas, it was very difficult to collect all the needed data in the fixed experimental sites. Unstructured data collection was also adopted to supplement or for verifying the data collected in the fixed sites. This integrated research project was completed by cooperation between the scientists of various disciplines from different institutions.

Main Research Contents

Characteristics of *Paulownia* related to the functions and structures of PCI - Growth pattern (Volume accumulation, biomass production and distribution among trunk, branch, leaf, flower, fruit, root and bark, and root growth); root distribution and its relationship with crop roots; and crown development, leaf index and light penetrating rate.

Functions and effects of PCI - Ecological effects (Microclimate, water balance, solar radiation and its distribution, energy balance,nutrition and material cycling); and Biological effects (PCI's effects on the growth, development, yield, and physiological status (photosynthesis, respiration, transpiration) of the intercropped crops (wheat, corn, and cotton), animal fauna and soil microbial community of PCI system.)

For the items of research abovementioned on the ecological and biological effects, the data was collected at multiple dimensions (time, space) of different planting models, so that the change of conditions in multiple dimensions of different factors can be explored, that provide the scientific foundations for building optimisation model.

Economic and social effects: Cost/benefit analysis of PCI, economic benefit from paulownia leaves as fodder, manure and building of mathematical model for comprehensive evaluation of PCI's economic and social effects.

PCI planting optimisation models -

Model optimisation using computerised modelling of solar radiation in PCI fields showing the relationship between energy balance and crop yields. Model optimisation to regulate yearly crop yield change. Rational techniques of cultivation and management of PCI. Model optimisation for economic benefits. Summarising the roles of technical service in the PCI extension.

Summary of Research Findings

Growth of *Paulownia*

Paulownia is one of the most fast-growing species in China. In a PCI system, 5-year old trees (four years after outplanting) can reach 17.73-23.5 cm or 19.9 cm with average dbh, and 6.4-9.2 m or 7.8 m at average in height with volume of 0.117 m^3/tree, that meets the standard for purlin timber production. Eight-year old trees (seven years after outplanting) are 24.1-35.5 cm or 29.5 cm with average dbh, 10.35 m in height with volume accumulation of 0.3719 m^3/tree, that meet the requirements for production of mid-class board. Eleven-year old trees are 29.1-49.0 cm or 38.38 cm with average dbh, 12.46 m in height and 0.5370 m^3/tree in volume accumulation, that met the requirements for production of plywood.

Paulownia is light-loving species and can only be planted at low intensity. It has large crown. Taking a *Paulownia elongata* tree in a PCI system with planting spacing of 5 x 20 m as an example, its crown covers an area of 22.09, 27.0 and 35.53 m^2 with leaf index of 2.53, 3.14, and 3.24 respectively at the ages of five, six and eight years. *Paulownia* is one of the species with lower leaf index in the North China Plain. According to the observations of Agricultural University of Henan Province, the leaf index of *Populous* with planting spacing of 3 x 6 m is 4.73 and 5.98 respectively at the ages of three and six years. While the leaf index of *Paulownia* at similar situation (planting spacing of 5 x 6 m) is 0.74 and 2.58 respectively at three and six years. The light penetrating rate through *Paulownia* crown is comparatively high even though the crown is big. The research on the light penetrating rates of single trees of different ages in Minquan County of Henan Province indicated that the penetrating rate was 11%, 27%, 37% and 10% higher through *Paulownia* crown than the crowns of willow, heaven tree locust and *Populous*. So, the vegetation under pure plantation of *Paulownia* can still grow and develop well. The weeds and shrubs are very difficult to control, that cause difficulties of management of pure *Paulownia* plantations. For this reason, *Paulownia* is usually intercropped with crops or mixed with other semi-sun loving species.

The *Paulownia* Root System and its Correlation with Intercropped Crops -

The growth and distribution of *P. elongata* roots were investigated. The results indicated that most of the roots of *Paulownia* were distributed under the tilling layer. A 7-year old *Paulownia* tree, for example, had 33.5% of roots distributed in 0-40 cm from soil surface, and only 1.8% roots in the top layer. This vertical distribution pattern of *Paulownia* roots is suitable for the growth of the intercropped crops because percentages of roots distributed in tillage layer (0-40 cm) are 80.1%, 97.4% and 94.6% respectively of wheat, millet, and corn. Concerning the horizontal distribution, *Paulownia* has large root system, but its horizontal distribution was dense and in small range. Before 3-year old, most of the roots were horizontally distributed within 0-2 m from tree stock. After 4-year old, *Paulownia* roots at the ranges of 0-2 m, 2-4 m and 4 m were far from tree stocks, 70-90%, 10-20% and lower than 10% of total roots. In view of these root characteristics, *Paulownia* could be considered as an ideal agroforestry tree species.

Biomass Production of *Paulownia* -

Biomass of *Paulownia* is main component in a PCI system. The quantity of *Paulownia* biomass reflects the productivity and the flow of materials and energy of the PCI system. Biomass production (fresh weight and oven-dry weight) of *Paulownia* was investigated yearly from one to eight years after outplanting, and the total biomass was divided into the following components - trunk (under crown), branches (big branches - diameter 8 cm, medium branches - 4 cm diameter 8 cm, and small branches - diameter 4 cm), leaves (leaf blades and stalks), bark, flower buds, flowers, fruits, roots (stock, thick roots - diameter 4 cm, medium roots - 0.5 cm diameter 1.5 cm, and small roots - diameter 0.5 cm), and litter. The result of the biomass investigation is as follows:

Components of *Paulownia* biomass - The biomass of each part in and for the whole plant of a 3-year old *Paulownia* were ranked as roots, trunk and leaves. Afer three years, the listing changed to branches and trunk, leaves, roots, flowers and fruits. The root growth of *Paulownia* is more dominant than of other organs before it is 3-year old. The growth of above-ground portion (trunk, leaves and branches) became faster with age of the tree. The proportion of biomass of each organ to total biomass was 31.9%, 25.31%, 21.32%, 17.19%, 4.27% and 1.4% for trunks, leaves, branches, roots, flowers and fruits respectively. Among which, the total amount of 30.98% of leaves, flowers and fruits fall off as litter. The cumulative biomass of one *Paulownia* tree at eighth year was 275.4 kg dry weight. Correspondingly, the total biomass per ha for different spacings of 8-year old *Paulownia* were estimated at 55,078, 27,535, 18,359, 13,769 and 11,016 kg/ha of 5 x 10, 5 x 20, 5 x 30, 5 x 40 and 5 x 50 m respectively.

The correlation of biomass components - The result of data analysis of biomass investigation showed that all the above mentioned biomass components, leaf area, biomass above ground and total biomass were closely correlated with square of breast height diameter and height (D^2H). All the coefficients were higher than 0.9. The main regression equations were:

$$LgWs = 0.9234LgD^2H - 1.7713 \ (r=0.9980)$$
$$LgWL = 0.7945LgD^2H - 1.8580 \ (r=0.9930)$$
$$LgW = 0.8925LgD^2H - 1.2409 \ (r=0.9982)$$

where Ws - weight of trunk;
WL - weight of leaves and W - total weight.

The underground biomass (WR) and above-ground biomass, branch (WBr) and leaf weight were linearly correlated with each other. The regression equations were:

$$WR = 0.2702W + 1.7543 \ (r=0.9910)$$

$$WBr = 1.8154WL + 4.1830 \ (r=0.9325)$$

Moreover, tree height and dbh were also linearly related as:

$$H = 0.3058D + 2.6456 \ (r=0.9893)$$

Based on the numerous equations, the biomass table for *P. elongata* was established. The result of verification of the table indicated that the table was usable.

Utilisation of *Paulownia* biomass - As mentioned above, the biomass of trunk and branch was 53.22% of the total biomass. About 63.5% of the *Paulownia* biomass can be easily used as timber and firewood. The root biomass was 7% and of foliage 30%. Full use of the foliage will increase the economic value of *Paulownia* trees. The leaves drop off due to the effects of early frost allowing not enough time for the trees to transfer the nutrient matters from leaves to root for storage before the leaves fall off. So the nutrient status of the fallen leaves is close to that of the fresh leaves (see Table 1). So *Paulownia* foliage can be used and the dropping off causes no harm to the growth of trees. The nutrient analysis of *Paulownia* foliage shows the presence of eight amino acids and trace elements such as Fe, Cu, Mn and Zn that are important to animal growth. The feeding experiments conducted in Shandong Province shown that 10-15% is a suitable proportion of *Paulownia* foliage as additive in fodder. The contents of N, P, K, Ca of the fallen foliage of *Paulownia* are 2.58%, 0.45%, 0.84% and 1.86% respectively. It is estimated from the above that 1 ha PCI field with 8-year old *Paulownia* can produce 13,940 kg leaves, 2,351.18 kg dry flowers, that is equal to 2,884.2 kg crude protein or 465.2 kg nitrogen when spacing of *Paulownia* is 5 x 10 m. Consequently, 4,411.74 kg leaves, 1,175.9 kg dry flowers, equal to 1,442.10 kg crude protein or 232.60 kg nitrogen for spacing of 5 x 20 m, 6,970 kg leaves, 587.9 kg dry flowers, equal to 712.8 kg crude protein or 116.3 kg nitrogen for spacing of 5 x 40 m.

Paulownia is also a good nectariferous species. There is about 0.0236 g pollen in a flower, from which 0.0473 g honey can be produced. A standard group of bees can collect 10-15 kg nectar during a flowering season. To sum up, *Paulownia* has many suitable characteristics, such as fast growth, deep root distribution, sparse crown structure, multipurpose (timber, fodder, manure and nectar sources), use when grown in agroforestry systems.

PCI's Ecological Effects on the Farming Fields -

In a PCI system, the combination of *Paulownia* and crop form an artificial multistorey community. Compared with the monocultural system, PCI system had different features in the ecosystem that caused uneven distribution of crop yields in the farming fields.

Modification of Microclimate in a PCI Field - Air temperature - *Paulownia* trees have versatile influence on temperature pattern. The tree crown serves as a barrier to obstruct the heat transfer, and reduces air mixing and evaporation resulting in increased air temperature. On the other hand, the shading of the crown and the consequent reduction in radiation led to decreased air temperature. The integrated effects of the two aspects led to form a special temperature pattern in a PCI field. During day time, the further the distance from the trees, the higher is the temperature. This is due to the shading effect which was more significant than the reduced air exchange. The temperature variation with the distance at night was opposite with that during the day. The lowest temperature was detected at the middle of tree rows. This is because the air exchange effect on increasing air temperature was greater than with the long wave radiation which decreased temperature. The denser the spacing, the more was the reduction of temperature. The day temperature at the middle during May was 2.3, 1.3, 0.5, 0.1-0.4 and 0.1 decreased respectively in the 5 x 6, 5 x 10, 5 x 20, 5 x 40 and 5 x 50 m spacing at 8-year old *Paulownia* in PCI systems. The vertical variation of air temperature was lower than in control. Temperature gradient near the trees and in the dense spacings were usually negative, i.e., temperature inversion took place, lapse rate occurred at shorter duration during the day, which might have been due to the effects of *Paulownia* shading and crown barrier. These effects resulted in the heat radiation taking place chiefly among the tree crowns, the cool air around the crown sinks. The lower levels thus became cooler than the upper levels.

Soil temperature - Soil temperature was mainly determined by solar radiation and longwave radiation. During the day, the temperature was mainly determined by solar radiation. The more radiation received, the higher was the temperature. During the night, long wave radiation intensity of the soil differed at different places of field because of shading effect of *Paulownia* crowns. In the middle between the tree rows, the radiation intensity was the highest and temperature decreased sharply. Compared with the control, the range of daily soil temperature variation was less, and higher the planting spacing of *Paulownia,* the greater the difference was between the PCI and control. Concerning the yearly variation of soil temperature, from late autumn to early spring, the soil temperature, especially at night, was higher in PCI than in the control.

Air humidity - The change and distribution pattern of relative humidity in a PCI field were very complex because of many factors. In general, during the day, the high relative humidity appeared in the middle between the tree rows and the relative humidity under the trees was low. Because the radiation received under the trees was less that lead to low evaporation. In the night humidity was high under the tree rows because the transferring rate of moisture was lower under the trees than in the middle between the tree rows. The comparison between the PCI field and control field indicated that the relative humidity in the night was higher in the PCI field. Due to the integrated effects of conductivity of the air, transpiration differences of *Paulownia* trees and crops during the day was very complex. In general, intercropping increased relative humidity, the moisture content in PCI field was higher than that in the open field in the night, but lower in the day time. The differences varied with the *Paulownia* spacing and age. Compared with the open field, there were 1.6, 0.9, 0.2 mb in moisture content reduction respectively of the 8-year old PCI models with *Paulownia* spacings of 5 x 10, 5 x 20 and 5 x 40-50 m.

Wind velocity - The PCI's effect on wind reduction of wind speed was obvious. Wind speed reductions of 30.4% and 26% were observed in 6-year old PCI field with *Paulownia* spacing of 5 x 10 m and 11-year old PCI field with spacing of 6 x 30 m. The research results indicated that more dense the *Paulownia* was planted, more reduction was the wind speed. With the same *Paulownia* spacing, the big reduction of wind speed can be observed in the fields with high density of leaf area. It was observed that the wind speed was reduced by 51.8% when the leaf area density was 1 m^2/m^2 (8-year old, 5 x 10 m, observed on 27th April just after the flowering period). When the leaf area density increased to 3 m^2/m^2 (23rd May), wind speed reduction of 73.1% was observed.

Solar radiation and computerised modelling - It was very important to study the solar radiation in PCI system because solar radiation affected other microclimate factors such as temperature, humidity, etc., and it was a main factor considered when preparing the model.

Crown shadow movement: The solar radiation received by the crops varied with the shading effect of *Paulownia* trees. The no-shading area within PCI system changed with sun'Hxelevation angle. The sunlight hours in a PCI system decreased at various levels. The bigger the distance was from the trees, the less the reduction of radiation received. The radiation distribution patterns were variable in different plantations with many planting spacings. Different sunlight hours were also observed under the same conditions. The hours of sunlight at 1 m east of the tree rows, for example, were 1.7, 2.8, 3.4 and 3.4 respectively in PCI systems with *Paulownia* spacings of 5 x 20, 5 x 30, 5 x 40 and 5 x 50 m.

Two-dimension distribution of radiation in a PCI field: The radiation status in a PCI system varied with the weather. In the cloudy days, there was no direct radiation and the radiation distribution only effected by the penetrating rate and shadow of the tree crown. On fine days, direct radiation was the mainstay. The radiation peak values (maximum and minimum) appeared on the contrary in the place between the tree rows and under the trees. In a PCI system with *Paulownia* spacing of 5 x 20 m, the maximum value of radiation appeared at 9 am at 1-2 m east of the tree rows, 10 pm at 3-4 m, 11 pm at 5 m, 12 pm at 6-14 m, 1 pm at 15 m, 2-3 pm at 16-17 m, 3 pm at 18-19 m. At same place, the relative radiation intensity was different at different phenological periods. In a PCI system with planting spacing of 5 x 20 m, the relative radiation intensity was 85% in the middle place between tree rows and 75% under the tree canopy during the period of flowering and early leaf development, 85% and 50% when the leaves were well-developed. At that time, the growth and development of wheat under the tree canopy was inhibited. The research findings presented that the lowest radiation intensity occurred in August because of the highest leaf area intensity. The relative radiation intensity in a PCI system changed with the ages also. Taking the PCI systems with planting spacing of 5 x 6, 5 x 10, and 5 x 20 m as examples, the relative radiation intensities in the middle between the tree rows were 80%, 92% and 97% respectively at three years after planting. They were 63%, 83% and 91% at five years and 42%, 61% and 82% at seven years after planting.

Computerised modelling of solar radiation: Recently, the study of radiation transfer through the tree canopy has given good results which inspired us to develop a computerised model with some information on the geometry of *Paulownia* canopy, biological characteristics of *Paulownia* trees and rules of radiation change. With the model developed, the radiation status in a PCI system can be measured with reference to tree height, trunk height, canopy width and leaf area intensity. The developed model was verified in the field and the result showed that the model was satisfying to be used in assessing the production and further research on crop yield forecasting and model optimisation.

Through the research on the modification of microclimate in PCI system, it was realised that *Paulownia* tree planting can achieve the microclimate conditions for crop growth in some aspects, and at least, no harmful effect on crop growth and development. But serious radiation deficiency occurred when *Paulownia* trees were planted too dense. So it is very important to control the planting spacing and adjust the radiation distribution in farming fields.

Water Status in PCI System -

The decrease of temperature during day time and increase of relative humidity led to the obvious decrease of evaporation in PCI. The evaporation of different PCI models observed in the middle between the tree rows from April-November were 1,011.7 mm in 5 x 6 m field, 1,196 mm in 5 x 10 m, 1,132 mm in 5 x 20 m, 1,204.8 mm in 5 x 40 m, 1,296.6 mm in 5 x 50 m and 1,334.4 mm in the control plots. The result showed that more dense the trees were planted, greater was the reduction of evaporation. Within a PCI field with uniform planting pattern, the evaporation varied with the distance of the *Paulownia* trees. The lower evaporation was observed in the place closer to the trees. The precipitation was slightly reduced in PCI fields due to the tree crowns' barrier effect. Compared with the open fields, there were only 3.5% and 1.8% reduction respectively in PCI models with *Paulownia* spacings of 5 x 6 and 5 x 40 m. During the winter, however, snow fall increased due to the reduction of wind velocity. It was observed that snow fall was 2,131.6, 1,820, 1,903, 1,915, 1,950 and 1,734 g/0.25 m^2 in the 5 x 6, 5 x 10, 5 x 20, 5 x 40, 5 x 50 m spacings in 8-year old PCI and control plots respectively. The abovementioned changes of water status led to the increase of soil moisture at various levels. The moisture content in the soil layer of 0-20 cm increased by 8.9% and 4.6% respectively in the PCI fields with spacings of 5 x 10 and 5 x 20 m. The observations in the fixed sites presented that, compared with the control field, the moisture contents in upper layer of soil increased, but decreased in the lower layer. The soil moisture content of upper layer (0-60 cm) was 24.2% in PCI field and 24.2% in the control field. The content of lower layer (below 60 cm) was 28.7% in PCI field and 29.5% in the control field. The observations match with the features of root system of *Paulownia*. When the *Paulownia* trees are planted in farmland, there is no negative interaction between trees and crops in water intake.

Energy Balance and Evapotranspiration of PCI System -

Through the systematic observations of total solar radiation, reflect radiation, wind velocity, temperatures (with wet and dry bulb thermometers), soil temperature and moisture contents of different layers in different PCI models, a description of energy balance of the PCI system was worked out. The net radiation and its components in a PCI system decreased when compared with control plots. However, the proportion of heat flux to net radiation was reduced, while that of latent heat flux and soil heat flux increased. The ratio of actual over potential evapotranspiration and soil moisture increased, resulting in less water deficit compared to control plots. *Paulownia*'s effects on these parameters depended on the tree density and growth stage, and their relative distance from one another. The modified energy balance was favourable to wheat growth during its heading and flowering stages under any *Paulownia* spacings, but the effect on wheat growth during grain filling in denser *Paulownia* spacings was due to the greater reduction in net radiation, perhaps brought about by the protective effects of the fully developed leaves on trees.

Soil Moisture and its Physical Features -

Soil moisture was one of the main factors affecting soil fertility. The parameters related to the physical characteristics of soil moisture were observed because the physical property of soil moisture was closely related to the soil ventilating feature. The result indicated that the volume weight of upper soil layers (0-20 cm) decreased with increase of distance from the trees. The maximum moisture holding capacity also increased with the distance from the trees. The volume weight of upper soil layer at 1 m to the tree rows was higher than the control.

Soil Nutrition Status -

Organic matter and nitrogen contents at 0-20 cm below soil surface decreased toward the trees. There was not much difference detected in available P, Ca and Mg. But available K was apparently higher within 5 m from the trees than further distance from the trees. Continuous measurements for three years at the age of 9-11 years old showed that there was not much difference in N contents at 0-60 cm below soil surface in the PCI field, but N contents at 80-100 cm below soil surface at a distance of 10 m from the trees significantly decreased while compared with the control. This could explain that *Paulownia* trees utilised nutrients mostly from lower soil layer (80-100 cm). It was also found that seasonal variation of available Ca and Mg was similar with that of the control. At 2 m from the trees, however, it increased at 0-20 cm below soil surface perhaps due to the decomposition of *Paulownia* litter.

Chemical Activities of Soil -

Enzyme, the biological catalyst extracted by microorganisms in their living activities, can accelerate the reactions of all biochemical activities of the soil. Results showed that at 0-20 cm below soil surface near the trees showed more activity of invertase, hydrogen peroxidase, etc. which led to the increase of decomposition of organic matter, composition of humus and oxidation of other components to increase soil fertility.

***Paulownia* Foliage as Manure** -

The above analysis shows that PCI caused crop-favoured changes in soil properties and nutrient status. It should be noted that all the above changes occurred when *Paulownia* foliage (80%) was not collected from the field. Local farmers usually collect *Paulownia* leaves for fodder. If all the *Paulownia* leaves are left in the field as litter, this will lead to greater changes in soil property and nutrition status in PCI system. In a 8-year old PCI system with *Paulownia* spacing of 5 x 20 m, it was estimated that 2.94 tons dry leaves were produced annually. The experiment of fertilisation was conducted using 2.94 tons of dry *Paulownia* leaves applied to 1 ha open field. The result indicated 30.6% increase of wheat yield and 19.8% increase of cotton yield.

Microorganism Fauna of PCI System -

The modification of environmental conditions in PCI field affected metabolism, quantity and variety of microorganisms, fauna and the product formation of metabolism. The density of bacteria and actinomycetes was higher in the PCI field than in the control plot and it increased towards the trees. The bacteria were mostly *Micrococcus* sp. in open field while *Pseudomonus* sp. in PCI field. It was also detected that there were more grey hyphae in PCI field than in the control; perhaps due to more humus. The activities of microorganisms brought the biochemical changes in the soil.

Animal Fauna of PCI System -

Animal fauna is one of the main indicators of the quality of an artificial ecosystem. An investigation on the animal species and their quantities was carried out in both the PCI and control fields during various periods of over-winter (January), wheat maturing (May), cotton growth (July) and cotton maturing (September). Over 60 species were recorded and final results showed: (1) the number of species and their quantities were higher in PCI system than in the control field. The main species were slug, caterpillar, tussock and bagworm moths, leaf beetles, parasitic wasp, ants, spiders, etc. (2) In the tree canopy layer, the dominant species were aphids in May, bagworms in July and September. The observations also indicated that there was no significant correlation between *Paulownia* spacing and the quantities of aphids and moths. (3) The underground animal quantities under the tree canopy were more than those outside the canopy in PCI system and open field. The dominant species were ants, grubs and earthworms.

Disinfectant Role of Leaf Secretion -

The aim was to study the disinfectant role of *Paulownia* leaf and the possibility to use *Paulownia* trees in purifying air. This study needed high level test conditions and so it was conducted in laboratory. The experimental results indicated that:

i) The compounds volatilised from *Paulownia* leaves can kill *Tubercle bacillus* (with a rate of 100%). Among the 36 tree species tested, *Paulownia*, *Sorbaria kirilowii* and *Hibiscus syriacus* showed highest antibacterial effect.
ii) *Paulownia* had no effect on *Staphylococus aureus*, but it was lethal to *Psudomanas aeruginosa* (38.8%).
iii) *Paulownia* leaf paste had strongest effect to kill fly among the 20 tree species tested. Under same conditions, it was only 1 min and 2 secs to kill a fly with *Paulownia* leaf paste, but 3 mins, 6 mins, 89 mins, 172 mins and 480 mins respectively for *Sorbaria kirilowii*, *Ginkgo biloba*, *Sabina chinensis*, *Quercus variabilis* and *Ulmus pumila*.

Growth and Physiological Variation of Intercropped Crops -

The modified microclimate was favourable for wheat growth during the period from sowing to flowering (October-April) when *Paulownia* was at dormancy. For instance, both emergence and filling of wheat intercropped under the *Paulownia* with spacings of 5 x 6 and 5 x 10 m were two days ahead than the control. The efficient filling and ears of wheat in PCI system were higher than the control. The efficient filling rate increased by 4.6-8% when compared with control. After late April, *Paulownia* entered the period of flowering and development of leaves that caused reduction of solar radiation in PCI system. Consequently, photosynthetic efficiency of wheat decreased which inhibited the filling of wheat, and finally, the quality of grain. It was measured that the 1,000-grain weight of wheat was reduced by 27% and 24% respectively in the 8-year old PCI with *Paulownia* spacings of 5 x 6 and 5 x 20 m when compared with control. Compared with control, photosynthetic rate of wheat in PCI system with *Paulownia* spacing of 5 x 20 m was slightly higher during *Paulownia* flowering when wheat was at heading stage. After *Paulownia* leaves were fully developed and wheat at filling, photosynthetic rate decreased by 9% under the *Paulownia* tree crown. Under the edge of *Paulownia* crown, photosynthetic rate increased by 17% and 40% with spacings of 5 x 20 and 5 x 40 m. Net photosynthesis was 6% higher and "noon rest" period was two hours shorter in both spacings. From crown edge to the middle of the tree rows, net photosynthesis, photosynthetic rate and biomass production of wheat increased by 18%, 5% and 10% respectively in the both spacings. From the above data, it can be seen that in a PCI system with *Paulownia* spacing of 5 x 20 m, for example, the net photosynthesis of wheat decreased in the area under the tree crown and increased in the area between tree crowns. According to observations of evaporation of PCI field and control field, the evaporation decreased in PCI field and the peak value of evaporation occurred earlier in PCI field than in control and evaporation rate was uniform in PCI field than in control. So, PCI system can more efficiently use the water than the open field.

The density of CO_2 in the air changed in PCI system. Compared with the control, CO_2 density in the PCI field with *Paulownia* spacing of 5 x 10 m decreased by 13-16% and it significantly correlated with photosynthetic rate of intercropped wheat (r^2 = 0.7022 - 0.951). CO_2 density with spacing 5 x 20 m decreased by 0.3-1.4% and it was not significantly related with wheat photosynthesis. It was estimated that the CO_2 density in PCI system was determined by effects of the competition of *Paulownia* and wheat and the reducing effect of *Paulownia* on air mixing.

PCI's effects on the growth of autumn crops were more apparent. *Paulownia*'s leaves were fully developed and the leaf area index increased after May. It was rainy season from July to September and radiation received by autumn crops was less which seriously inhibited crop growth especially the light-loving species such as cotton and corn. It was observed that the early vegetative growth of cotton and corn in PCI system did not significantly differ with that growing in the open field, but the later vegetative growth was inhibited by the insufficiency of radiation. During the period from July to August, the nutrient and water were sufficient, and CO_2 absorption rate increased 10-30% and transpiration rate by 3-15%. Photosynthetic rate of crops also increased. So the vegetative growth of the crops in this period was not inhibited by the trees. The biomass production of the crops in PCI system was even higher than that in the open field. During dry season (September-October) the conductive rate of CO_2 and transpiration decreased by 10-40% with corresponding decrease in photosynthesis. This was more unfavourable to cotton than to corn. Compared with that in the open field, the photosynthesis of cotton bolls in between the tree rows decreased by 20%. Greater photosynthetic decreases were recorded under tree crowns due to the shade of *Paulownia*. Fast vegetative growth had the plant or the cotton boll higher light saturation point than other organs. It was very important to control the vegetative growth of cotton through management means. The biomass investigation result also presented the same tendency. Biomass of single cotton plant, for example, was higher in the PCI system with *Paulownia* spacing of 5 x 20 m than in the open. But biomass of single plant of corn was lower in PCI system than in the open field. Only at the middle between the tree rows in *Paulownia* spacing of 5 x 40 m PCI field, it increased in the open field. With regard to the cotton bolls and corn cobs, compared with that in an open field, cotton bolls decreased by 66% and corn cobs decreased by 9.2% in the PCI field with *Paulownia* spacing of 5 x 20 m, but cotton bolls increased by 36% and corn cobs increased by 77% in spacing of 5 x 40 m.

Crop Yields and Quality in Various PCI Models -

Wheat yield - PCI provided favourable growth conditions for wheat. Wheat's light saturation point was low (about 50% of the total solar radiation), so that wheat grew well in PCI system. The competition for light between wheat and *Paulownia* was not serious as that between *Paulownia* and corn or cotton. So wheat was a very promising crop for intercropping in PCI system. Yield of wheat in the PCI system varied with the *Paulownia* spacings and ages. Seven-year continuous observations presented the following changes in wheat yield in the PCI systems when compared with the open field. In the first three intercropping years, the yield remained the same with *Paulownia* spacings of 5 x 6, 5 x 20, 5 x 40 and 5 x 50 m, small increase was detected in the field of 5 x 10 m *Paulownia* spacings. In the fourth year, yield reduction was 12% and 7% respectively in the fields with *Paulownia* spacings of 5 x 6 and 5 x 10 m, and about 5% increase was detected in other spacings. The main increase was in area between tree crowns. In the seventh year, the yield decreased by 30-35% in 5 x 6 m, 25-30% in 5 x 10 m, 6-7% in 5 x 20 m, and increased by 4-5% in 5 x 40 m, 8-10% in 5 x 50 m.

Quality of wheat grain - The grain quality test was conducted in different spacings of 8-year old *Paulownia* in 1989. Samples were collected at 1-2 m (under crown), 4-7 m (edge of the crown) from the trees and middle between two tree rows with three replicates. The results showed that the highest 1,000-grain weight was at the middle between the two tree rows in the 5 x 20 m. Compared with control, 27% and 24% reduction was detected in the spacings of 5 x 6 and 5 x 10 m. While, the 1,000-grain weight in the large spacings was more or less the same with the control. The crude protein contents were always higher in PCI system than in control, especially from the fields with *Paulownia* spacings of 5 x 6 and 5 x 10 m and under the crown of 5 x 20 m *Paulownia* (with average content of 23.74%, it was 87% increase when compared with the control). The lowest crude protein content in PCI system was detected in the middle of two tree rows in 5 x 20 and 5 x 40 m that was only 15.74%, but it was still 23.9% higher than in the control. There was no significant difference of total carbohydrate contents between PCI and control. Starch contents of grain in the PCI systems were mostly lower than control. Exception was that at the edge of *Paulownia* crowns and middle of tree rows in 5 x 40 m the starch content was 6.75% and 1.6% higher than control. It was concluded that the variation trends of wheat grain quality in PCI system were significant increase of the contents of protein, fat, slight decrease in starch content and slight increase in mineral. So in general the quality of wheat grain in the PCI system apparently became higher compared with the control.

Quality of corn - Twenty-one samples of corn were collected at different distances from *Paulownia* rows in the 5 x 20, 5 x 40 m for quality test. The results showed that 1,000-grain weight of corn at any distance from the trees was higher than control. Nearer from the trees, higher was the 1,000-grain weight. The highest was 244 g at the middle of two rows in the 5 x 40 m, which was 27.7% higher than control. Crude fat contents of corn from PCI system were higher than the control. The highest were at middle of 5 x 20 m (4.41%) and 5 x 40 m (4.15%) which were 12.8% and 6.1% higher than control. Crude fiber content of corn from PCI system was slightly higher than control. Starch content of corn from PCI system was slightly lower than control. All the data showed that the quality of corn from PCI system was higher than control.

Quality of cotton fiber - The analysis was conducted by Beijing Fiber Analysis Institute. The intercropped cotton was lower than control. The quality cotton under crown, edge of the crown and the middle of two *Paulownia* rows were 5,986.0, 5,988.5 and 6,217.5 m/g respectively, while that from control plot was 6,785. The average fiber strength (g) from PCI field was 11.8% higher than control, though there was not much difference among different distances in the PCI system. Similarly, break-off length (km) and coefficient of maturity were 1.6-11.4% and 6.7-30.8% lower than control. Photoelectric pillar length (mm) increased in PCI system than control (28.30 mm) except (27.07 mm) under the tree crowns on east side and highest value (29.23 mm) was from plants at the middle of two *Paulownia* rows. There were very few differences in the values of ginning cotton (35-36%) among samples from PCI system and control. It can be generalised that the fineness of cotton fiber from PCI field decreased, but other quality index increased so that the quality of cotton from PCI system was similar to control.

Economic Benefits and Social Effects of PCI - Comparison between PCI field and monocultural crop field - Compared with the monoculture of crops, PCI system had different economic benefits due to the input/output of management of trees. Taking PCI model with *Paulownia* spacing of 5 x 20 m as an example, the average volume increase was up to 6.75 m^3/ha/yr valuing 3,372 Chinese Yuan (RMB)/ha/yr. With the income from the branches and foliage, the total average output can reach 3,875 Chinese Yuan (RMB)/ha/yr which was equal to the value of 3,875 kg wheat, which was almost equal to that from wheat in open field. The cost/benefit ratio of monoculture of crops (wheat and corn) was 1:2.6 at average. It increased to 1:4.2 in the 7th intercropping year of "*Paulownia* + wheat + corn" model with *Paulownia* spacing of 5 x 20 m, 1:3.6 when *Paulownia* planted at 5 x 40 m. When the crops were wheat and cotton, the ratio was 1:1.6, it reached 1:3.6 when *Paulownia* planted at 5 x 20 m and 1:2.8 at 5 x 40 m.

Comparison among different PCI models - According to the investigations on the yield of different PCI models in low and middle yield area (sandy or sandy loam soil) of Minquan County, Henan Province, the equations for estimation of economic benefit were developed. Denser the planting spacing of *Paulownia* was, higher was the economic profit. The best economic benefit was obtained in 7th year from *Paulownia* rows at 5 x 20 and 5 x 30 m. There were other intercropping models at Minquan, i.e., "*Paulownia* + shrubby ash + crops (PSC)" and "*Paulownia* + grape (PG)". The economic benefit was 15.5% higher than that of control (monoculture of crops), and PG's economic benefit was 13.9% higher than that of control (pure grape plantation). Both of them were also promising models for this area.

Methodology of economic evaluation of PCI - It remained a problem how to rationally evaluate the economic effects of the special land use system - PCI. If we used single objective evaluation, i.e., using net value as the only objective for evaluating the PCI models, the result was denser the *Paulownia* trees planted, higher the economic benefits. This was because *Paulownia* as a fast-growing species gave high economic value and the extra output, compared with the pure crop plantation, could cover the decrease of crop yield affected by opposite effect of *Paulownia* trees' shade. But the models with dense *Paulownia* spacings were very difficult to be accepted by the local farmers of the Huang-Huai-Hai Plain Agricultural Area. For this reason, a multiple objective evaluation method was used to solve this problem. The four objectives were: Net present value, guaranteeing of grain production, land expected value and benefit/cost rate. The four objectives were not at the same level of importance and were given different weights to draw an equation to determine the scores of certain PCI model in certain period:

$$Y(m,n)=\frac{Z1(m,n)x3+Z2(m,n)+Z3(m,n)+Z4(m.n)x2}{7}$$

Social effects of PCI development - The social effects of PCI can be described and main points are as follows:

1) The plain areas were very short of timber supply and PCI system increased timber availability.

Henan Province, for example, had a total PCI area of 1 million ha with a standing volume of 5.5 million m^3 with annual increment of 2 million m. The total timber production from the state forest farms was only .16 million m^3 per year which was only about 10% of *Paulownia.*

2) *Paulownia* timber is an important export item and most of it is from the Huang-Huai-Hai Area (90%). In 1984, 114,702 m^3 *Paulownia* logs and 16,910 m^3 *Paulownia* boards were exported that earned US$7.21 million.
3) The large amount of branches from *Paulownia* trees are good sources for firewood and each tree produced 14 kg branches for firewood per year in the first eight years. This helped the farmers economically and soil fertility also increased due to the foliage returning to the field.
4) *Paulownia* foliage is a very good resource for manure and fodder. According to a survey made, there were 24 million *Paulownia* trees in Luyi County of Shandong Province. The *Paulownia* trees produced 354,000 tons of leaves which contained about 9,310.2 tons of nitrogen, equal to 20,239.56 tons of urea, crude protein 57,723 tons and crude fat 36,679 tons. 23,244 tons of dry flowers were produced which contained about 1,036 tons of nitrogen, equal to 2,253.7 tons of urea and 6,427 tons of crude protein. The total from both leaves and flowers in the county led to 22,493 tons of urea.
5) PCI development improved the economic condition of the rural area. Taking Minquan County and Luyi County as examples, the income increased by 15.8% and 10.7% respectively, due to the extension of PCI. In some particular Xiangs, this figure reached 19.0%.
6) PCI development also promoted agricultural modernisation. In the provinces of Henan and Shandong, about 70-80% of *Paulownia* timber was used as building materials, the remaining for furniture and other timber products that increased the number of local manufactures increasing employment. At Kongchangcun of Lankao County, Henan Province, there were 196 households (73% of the total households) engaged in processing and manufacturing of *Paulownia* timber. The 1988 statistics of Minquan County of Henan Province showed that among the total investment for agriculture, 96.7% (31.11 million Chinese Yuan) was from the farmers themselves and the total input from the farmers, 31.5% (10.25 millions CNY) was from *Paulownia*. The capital input of the local farmers was mainly for farmland construction, purchase of farm machinery which modernised agricultural operations.
7) PCI development also improved the local education and health conditions. An obvious effect of PCI development was to improve the housing condition of the farmers and availability of timber was met by 50% needed for house construction in Minquan. The farmers also improved the conditions of schools and other public welfare projects using the income from *Paulownia*, that promoted better standards of living.
8) PCI development also improved the work condition and efficiency of the farmers.

Selection and Optimisation of PCI Models -

In order to select a rational farming system, it was considered to combine the management practice with multiple objectives. It was important that the selected models should achieve both high economic benefit and crop yield. In this way, the aspects of ecology, biology, economics and sociology were combined to achieve the main objective.

Solar Radiation Distribution in PCI Field -

According to the results obtained by computer model, after second year of intercropping, there were no adverse effects by *Paulownia* trees on the crop yield in the tested spacings from 5 x 10 to 5 x 50 m. During third year, *Paulownia* planted at spacing of 5 x 10 m had slight adverse effect on the crop yield which was not significant. At fourth year, in 5 x 20 m spacing the crop growth was slightly less. At sixth year, the optimum spacing for *Paulownia* was 5 x 40 m.

Relationship between Energy Balance and Crop Yields -

Wheat yield was closely related with the energy balance of the field. A project equation was drawn to estimate the wheat yield through the energy balance status and the optimum *Paulownia* spacings were 5 x 30 and 5 x 35 m at the seventh intercropping year. With the optimum spacings, the wheat yield in PCI field was about 100 kg/ha higher than in open field.

Crop Yield Change with the Ages of *Paulownia* -

The following data was collected during the crop yield investigation in the low (sandy soil) and middle (sandy loam soil) yield areas of Minquan County of Henan Province: In the PCI models where the crops were wheat and corn, the total yield of the first seven intercropping years was reduced by 0.01% and increased by 7.1% respectively in 5 x 20 and 5 x 40 m in the low yield field. However, there were 15.2% and 2.2% yield reductions respectively with spacings of 5 x 10 and 5 x 20 m, but an increase of 5% was detected in 5 x 40 m field. In the PCI models in which the intercropped crops were wheat and beans, there was 0.1% increase in 5 x 20 m and 7.8% increase in 5 x 40 m in low yield field. In middle yield field, it was reduced by 8.1% in 5 x 10 m. An increase of 0.9% and 4.7% was detected in the 5 x 20 and 5 x 40 m spacings respectively. In total it was not lower than in the open field. The optimum level at the seventh year was with *Paulownia* spacing of 5 x 20 m and, at the 10th year, 5 x 40 m.

Determination of Rational Silvicultural Techniques -

Three aspects are discussed - row orientation, distance between rows and trunk height. **Distance between rows** - The relationship between *Paulownia* spacing and crop yield was described above. The following explains the relationship between planting spacing and growth of the trees. Taking the 9-year old 5 x 6 m *Paulownia* plantation's standing volume (100.04 m^3) as 100%, the volume of the plantations with spacings of 5 x 10, 5 x 20, 5 x 40 m were 64.5%, 30.1% and 17.1% respectively. But their single tree volumes were 111.2%, 105.4% and 119.9% respectively of those planted at 5 x 6 m (0.3176 m^3/tree). We can deduce the following that *Paulownia* trees should be planted initially at spacing of 5 x 10 m and then thinning (50% thinning rate, i.e., one thin row for every two rows) at the fourth, seventh year and cut down all the trees at the 10th year. Using this management pattern will produce 29.76 m^3/ha (111%) and 4,816.5 kg/ha, 5,796.5 kg/ha more, respectively in timber, dry leaves and branches in a rotation of ten years than that initially planted at spacing of 5 x 40 m. If *Paulownia* trees initially planted at 5 x 20 m, and thinned 50% at seventh year and cut down all the trees in the tenth year can also produce 69.4% more timber with extra dry leaves of 3,467.5 kg/ha and branches of 2,932 kg/ha than those initially planted at spacing of 5 x 40 m.

Orientation of tree rows - The experimental results showed that there was no significant difference between the E-W orientation and S-N orientation in width of belt in which the crop yield decreased in 9-year old PCI models with spacing of 5 x 40 m. The width in S-N orientation model was 8.6 m and 9.2 m respectively for wheat and corn, and 8.8 m and 9.3 m in E-W orientation. The percentages of yield reduction differed significantly between the two types of orientation. The reduction percentage of S-N orientation was 6.7% and 21% respectively for wheat and corn, but was 22% and 36.2% in E-W orientation.

Trunk height and crop yield - The lower the trunk height, higher the reduction of crop yield was. In a 9-year old PCI model with spacing of 5 x 40 m, the yields of wheat and corn were reduced by 14.2% and 17.2%. When the trunk height was 2.8 m, the values were 5.1% and 8.9%. So it was very important to prune the trees in PCI system to improve the light penetration through crowns.

Model Optimisation in the View of Economic Benefits - Classification of PCI models -

The models practised in the Northern China were mainly the following: A: *Paulownia* + wheat + corn; B: *Paulownia* + wheat + bean; C: *Paulownia* + wheat + cotton. For all the three groups of PCI models, the *Paulownia* trees were planted at six different spacings, i.e., 5 x 6, 5 x 10, 5 x 20, 5 x 30, 5 x 40 and 5 x 50 m. The economic analysis of the three planting patterns with different *Paulownia* spacings were conducted with the ages from 1-12 years. The results of the analysis were used for determining the optimum planting patterns and suitable planting spacings and rotations.

Choice of objectives for economic evaluation - Single objective evaluation of the PCI system was not satisfactory. If the net economic profit is the only objective of evaluation, the result should be the denser the *Paulownia* trees were planted, the higher the economic profit. If we select the net present value as the only one objective the result indicated that with planting spacing of 5 x 6 m the optimum rotation was 11 years. But in Northern China Plain food production is important, i.e., PCI development must guarantee the production of grain, cotton and oil. To meet the above, a multiple objective evaluation method was used. The selected objectives and their relative values were as follows: Net present value with weight of 3, benefit/cost rate with 1, land expected value with 1, and relative wheat yield with 2 (when the rate 90% scored as 2, 80-90% scored as 1 and P% scored as 0).

Choice of optimum PCI model - The results of comprehensive evaluation of PCI models under the condition of discount rate of 8% showed that Model 3 (*Paulownia* + wheat + cotton) with *Paulownia* planting spacing of 5 x 40 m and rotation of 11 years. The four parameters of optimal model were 50,615.4 Chinese Yuan (RMB)/ha in net present value, 314,56% in cost/benefit ratio, 88,625.25 Chinese Yuan (RMB)/ha in land expected value and 90% in wheat relative yield.

Optimisation of PCI models - The abovementioned PCI model can be further optimised in the view of dynamics. We can design two dynamic PCI models as follows: (a) *Paulownia* trees initially planted at spacing of 5 x 10 m, after two times of thinning at 50% thinning rate, the spacing became 5 x 20 m after first thinning at year 5 and 5 x 40 m after second thinning at year 7. The final harvest of *Paulownia* trees can be conducted at year 10. It is estimated that the four parameters of this new PCI planting model are 54,937.2 Chinese Yuan (RMB)/ha in net present value, 326.34% in cost/benefit ratio, 95,142 Chinese Yuan (RMB)/ha in land expected value and wheat relative yield greater than 90%. (b) *Paulownia* trees initially planted at spacing of 5 x 20 m, in year 7, one row of *Paulownia* trees can be cut down for every two rows and replanted with *Paulownia* seedlings. Four years later, the older trees reached 11-year old and can be cut down and replanted with new seedlings. In this way, an uneven-aged, two-storeyed structure of *Paulownia* plantation formed. In this case, the parameters will be 58,956.9 Chinese Yuan (RMB)/ha in net present value, 348.46% in cost/benefit ratio, 100,230.6 Chinese Yuan (RMB)/ha in land expected value.

Conclusions

The above analysis of PCI has indicated that it was a suitable farming system in Huang-Huai-Hai Plain Agricultural Area. It was particularly suitable for development in the low-yield or middle-yield farmland. Following conclusions can be summarised from above analysis:

i) In most situations, the initial planting spacing of *Paulownia* can be 5 x 20 m. After a 50% thinning (one row every two rows) in year 7, the spacing becomes 5 x 40 m and keep this density till year 10-11 until the time of main harvest. In the area with high requirement for small logs, the initial planting spacing can be 5 x 10 m, then thinning at year 4 and year 7 for small logs. In the high-yield farmland, the paulownia trees can be planted at spacing of 5 x 25 m or 5 x 30 m and thinning to 5 x 50 or 5 x 60 m at year 7-8 and keep this density till the main harvest in year 10-12 for production of large logs.

ii) For keeping stable ecological environment of farmland and continuous production of timber, fodder, firewood and manure, uneven-aged, two-storeyed management methods described in previous section can be adopted.

iii) The orientation of *Paulownia* tree rows should be at S-N direction. Under the prerequisite of no obvious harm to tree growth, pruning should be conducted to maintain appropriate trunk height and leaf density.

iv) Concerning the selection of crop species, wheat is ideal summer harvest crop. It is very important to select appropriate autumn crop. The autumn crops should be shade-tolerant. Intercropping model selection is very complex work. It should combine all the factors of ecological effect, crop yield, economic and social effects. The objectives of the PCI development should try to obtain maximum economic benefit from unit land and efficiently improve the ecological environment of farmland, so as to promote the productivity. Meanwhile, both direct and indirect benefits should be considered. The advantages of a good farming system is only possible when it reaches an appropriate scale and form a complete production system. The development of PCI system, for instance, needs the development of related industries such as processing of *Paulownia* foliage as fodder and wood for timber.

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The Correlation Between Windbreak Influenced Climate and Crop Yield

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ABSTRACT

To establish relationship between the crop (wheat) yield and microclimatic factors, a multivariate regression equation of yield was established. The main points of analysis were as follows:

1) A reduction of 1 m/s of wind speed at a given plot caused by the shelter belts increased the crop yield by 18.75 g/m² (25 jin/mu) and raised the average 1,000-grain weight by 0.74 g.

2) A reduction of the saturation deficit of the air by 1 mb caused by the shelter belts increased the crop yield by 6.81 g/m² (9.1 jin/mu) and raised the average 1,000-grain weight by 0.17 g.

3) A reduction of 1% of solar radiation caused by the shadow of the shelter belts decreased the crop yield by 5.47 g/m² (7.4 jin/mu) and average 1,000-grain weight by 0.07 g.

4) An increase in moisture content of soil by 1% (wt w.r.t. dry soil) due to the reduction of evaporation caused by shelter belts increased the crop yield by 17.27 g/m² (23 jin/mu) and the average 1,000-grain weight by 0.42 g.

Introduction

Much research has been done on the relationship between the windbreak influenced climate and crop yield (Fu, 1963; Li *et al.*, 1959), which has helped to understand the windbreak influenced climate and its effect on crop yield. Based on the large numbers of measurements of radiation, temperature, wind and humidity in a windbreak square, the variation of climatic factors and crop yield in shelter beds were examined by using regression analysis. Through the comprehensive analysis on the correlation between climatic factors and crop yield, a quantitative expression of crop yield against climatic factors was obtained. The relative importance of each factor and its potential effect on crop yield was determined. These supported the correct evaluation of protection and economic effects of windbreaks, and for the modification measures and designations.

Site Description and Research Methods

Site Description -

The site plot is at Houtun, Shenxian County of Hebei Province, which is located at the ancient course of the Houtun River in the Heilonggang Reaches. The land is low-lying and the soil alkaline. The climate is temperate, semi-moist monsoon climate region. The windbreaks were established from 1958, beginning with the alkalinity-improving based farmland capital construction. Mixed shelter belts were planted along ditches and roads, and tree patches and orchards were planted in the heavy alkaline soil. Then 3,200 mu (1 mu = 1/15 ha) of farmland was latticed by shelter belts into 52 windbreak square systems. The most typical square was chosen for the research. The characters of four windbreaks are shown in the table below. The south and north are primary windbreaks, with a distance of 263 m. The east and west are secondary windbreaks with a distance of 217 m. The square area is about 83 mu, and the crop was winter wheat (variety code 7123) sown in four rows. The between-row distance was 70 cm. The crop height at mature period was 90 cm.

Table 1. Details of four windbreaks, species composition and soil porosity

Windbreaks	Height (m)	Width (m)	No. of rows	Species composition	Porosity
East	12.0	14.3	4	*Populous tomentosa, P. canadensis, Salix matsudana, Amorpha fruticosa*	0.41
West	7.8	10.6	4	*S. matsudana, P. tomentosa, A. fruticosa*	0.41
South	9.4	15.2	8	*S. matsudana, A. fruticosa*	0.59
North	10.3	15.2	6	*S. matsudana, A. fruticosa*	0.49

Instruments -
Robinson anemometer and hand holding anemometer, ventilation dry and wet bulb thermometer, pyranometer and pyroelectrical net radiometer, and other instruments were used in the study. The soil humidity was measured by the soil digging method (three depths: 0, 10, 20 cm and once every five days). The observation period began at the heading period of wheat in mid-May, and ended at the mature period in mid-June. Fine days were chosen with measurements taken every half hour or one hour for 24 hours.

Analytical Methods -
The air flow and humidity siHxation in the square were established based on the windspeed and saturation deficit distribution data under SSW winds. This was because at that period of time the prevailing winds were hot, dry winds from the SSW. The radiation distribution pattem in the square was expressed by the percentage of daily total direct radiation at each point over the unsheltered direct radiation. The total radiation data were not used because the distributional trend of daily total direct radiation was similar to that of the total radiation. The use of total radiation data would have caused statistical errors, since both the diffusion as well as the reflection radiations would have had to be estimated. Additionally, there were, only seven points available.

The soil moisture content was expressed by the average soil moisture in the depth of 0-20 cm. The soil moisture investigation was conducted regularly, and the change was slower compared with the air. It was not accurate to use a certain investigation of soil moisture and compare it directly with other climatic factors.

The crop yield in the square was expressed by the mean yield of the sample plot. If the sample yield was directly used, the real tendency of yield distribution could be concealed. The layout of the plots were at 1, 3, 5, 7, 9, ... times of the tree height from south to north and from west to east. The total

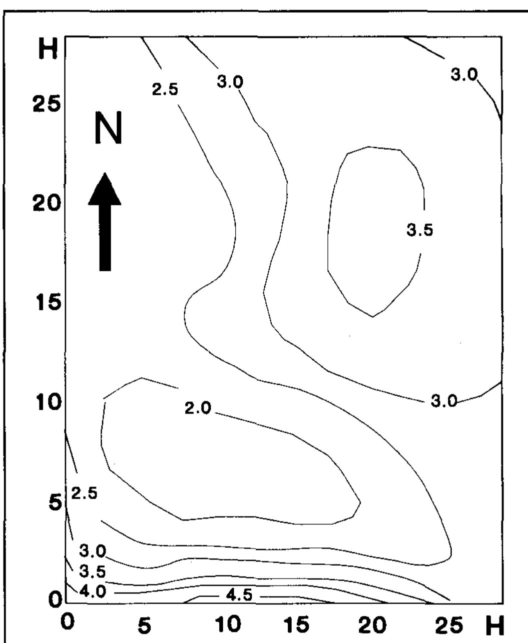

Fig 1. Windspeed distribution in the square (m/sec) (wind direction SSW). shown by isovalue lines

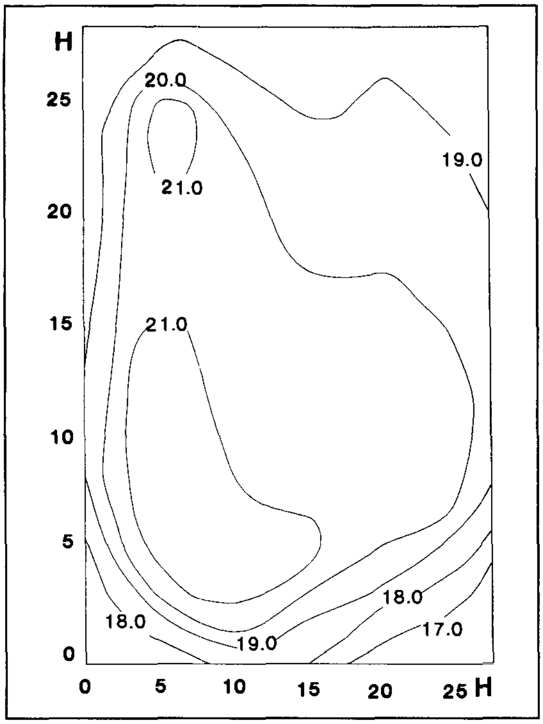

Fig 2. Soil moisture distribution in the square (%)

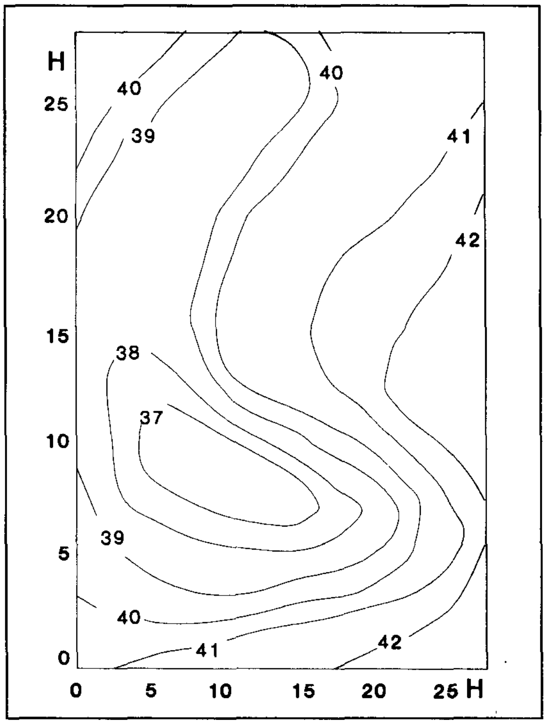

Fig 3. Saturation deficit distribution in the square (m bar)

number of the one-square meter sample plots were 130. Yield data included the grain weight per sample plot (g/m^2), and the thousand grain weight (g).

The air temperature distribution was not considered here, because in the whole period, obvious air temperature distribution patterns were fairly uniform.

Experimental Results

The Distributional Characters of Important Microclimatic Factors in the Windbreak Square -

Windspeed - The variance of windspeed can cause the variance of other factors. Generally, the windspeed distribution in a windbreak square varied from the windbreak structure, geometrical characters and wind directions. But for a windbreak square with similar structure of shelter belts around the square, the windspeed distribution was mainly dependent on the wind direction (Table 1).

Naturally, the wind direction varied from time to time, therefore, the windspeed distribution was changing constantly. But whatever the change, there was always an obvious relation between the wind direction and windspeed distribution. Results showed that there was an obvious relationship between horizontal windspeed distribution and wind direction in windbreak square (see Fig. 1):

(1) The windspeed was greater in the lower part of the windbreak. The cause was mainly from the tubing effect in the lower part of a permeable windbreak.

(2) Inside 3H of the windbreak leeward, the iso-windspeed lies were very dense and the horizontal windspeed gradient was very great.

(3) From 3H-9H leeward, it was a low speed region, the lowest speed center was often of closed-type.

(4) From 15H-25H leeward, the combination of the overpassed flow and the penetrated flow formed a weak closed and high speed region, the windspeed was about 80% of the open.

(5) In the windward of the next windbreak, the horizontal windspeed gradient was very small, and the iso-windspeed lines were far more sparse compared to those in the leeward.

Radiation - The horizontal radiation distribution difference in shelter belt was another important cause for the formation and influence of microclimate and crop yield. In a certain latitude and a certain period of time, the radiation distribution difference in shelter belt was mainly affected

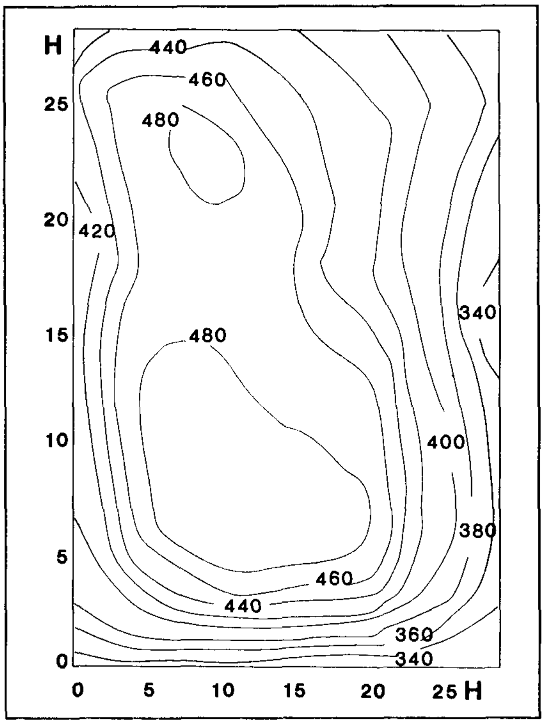

Fig 4. Distribution of crop yield (g/m^2)

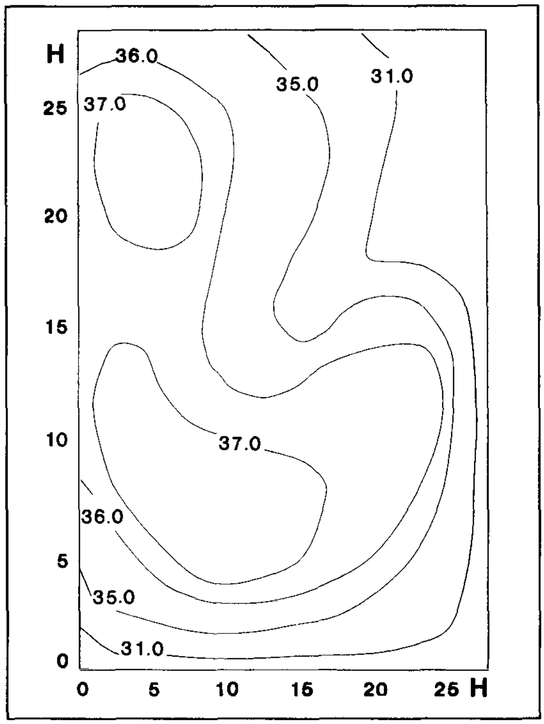

Fig 5. Distribution of thousand grain weight (g)

by the windbreak height and orientation. The different points in shelter belt received different shading, and the radiation was certainly different. In our experiment, the direct radiation distribution in shelter had the following characters:

(1) Nearer to the windbreak, lesser the radiation.

(2) The points further than 10H received 99% of radiation received in the open. That is, essentially there was no radiation effect.

(3) Of the four windbreaks, the north windbreak had the least effect on the radiation in shelter.

(4) The effect of the south windbreak on radiation was less than 1H, but in this area, the effect was very strong. In 0.75H, for example, for the whole 2nd half of the year through the Autumnal Equinox, the Winter solstice for the Spring Equinox, direct radiation was totally shaded by the windbreak. There was part radiation only in the lst half of the year.

(5) The east and west windbreaks had the largest area of shading, which could be the entire windbreak square. The direct radiation could be reduced by 5%, up to 2-3H.

Soil moisture - For the fully moistened soil, evaporation is only dependent on the meteorological conditions. The site plot was well irrigated and the soil was basically moistened. Therefore, the soil moisture distribution in shelter belt was mainly dependent on the microclimatic distribution. As can be seen from Fig. 2, the soil moisture distribution and the windspeed distribution were very similar. In the leeward side of south and west windbreaks, the low speed area corresponded to an area of high soil moisture. This was obviously due to the reduction of turbulence and evaporation. The low soil moisture in the adjacent areas to windbreaks was probably due to tree transpiration, high windspeed, and drainage ditches dug along the windbreaks.

Saturation deficit - If the effect of the increase of air vapour of windbreaks was not considered, windbreaks had no direct effect on the saturation deficit distribution. The distributional differences of saturation deficit in shelter belts were mainly the result of the differences of soil moisture distribution which can be seen clearly in Fig. 3. Here the low soil moisture and high saturation deficit corresponded to a high moisture and low saturation deficit.

Crop Yield -

The yield distribution in shelter belt was generally affected by the two aspects of climatic factors. One was the average water and heat situa-

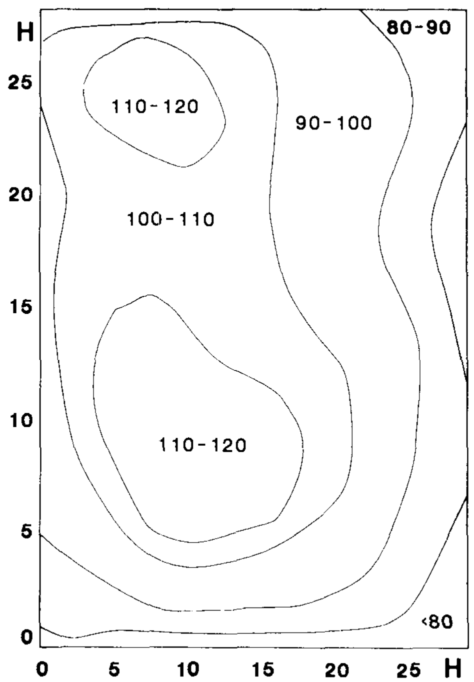

Fig 6. Distribution of relative crop yield (%) (mean yield as 100%). (For further details see text)

tion in the whole growing period; the other was calamitous weather conditions. For instance, in a certain place and for the crop growing period, if the prevailing wind directions were different from the hot, dry wind directions, the yield distribution was mainly determined by the leading direction. For the experiment here, the prevailing wind direction and hot dry wind direction both were SW. Therefore, the effect of average water and heat situation in shelter belt on crop yield was identical to the hot dry wind. From Figs. 4 and 5, it can be seen that the distributions of two elements were slightly different, but the distributional tendency was closely related to the distribution of microclimatic factors.

In Fig. 4, if the mean sample yield was 100% and the sample yields of other points compared with it, then Fig. 4 can be redrawn as Fig. 6 where it is easy to see that the yield distribution in shelter belt has the circle character. The high yield area over the average sample yield is in the inner part of the circle; the low yield area is in the outer part, and the further the distance, the lower the yield. Thus, the area of highest yield is identical to the area of largest protection in shelter belt.

Establishment of Regressive Equation for Crop Yield -

As stated above, there was a close relationship between distribution of crop yield and climatic factors. If compared carefully, it can be found that the yield distribution is relevant to a certain factor but not completely identical. This shows that the yield distribution in shelter is not simply affected by one factor. If Ai is an arbitrary point in shelter belt (i = 1, 2, ...) and Yi, vi, di, qi, Ri are yield, windspeed, saturation deficit, soil moisture, radiation. Supposing there is a linear relation between Yi and vi, di, qi, Ri, then:

$$Y_i = b_0 + b_1V_i + b_1d_i + b_3q_i + b_4R_i + e_i$$

Therefore, if there are enough points and relevant data of various factors, a regression equation can be obtained, which can help to determine (Fig. 6) the greatest or least effect on crop yield.

Where e_i represents the effect of other factors on crop yield.

The data were obtained through measurements on the above distributional figures, in which lines at one-H interval were drawn from S to N and from E to W, each factor was read through 27 x 27 = 729 readings. If the effect of other factors was omitted, the regression equations are:

$$Y_1 = -118.43 - 18.75v - 6.8d + 17.27q + 5.47R \qquad R_{m1} = 0.89$$

$$Y_2 = 29.00 - 0.74v - 0.17d + 0.42q + 0.07R \qquad R_{m2} = 0.87$$

Here Y_1 is the sample grain weight (g/m^2), Y_2 is sample thousand grain weight (g). Rm is the compound coefficient.

The parameters b_1, b_2, b_3, b_4 represent the effect of per unit change of each factor. So we have:

1) If the windspeed is reduced 1 m/s by the square the sample grain weight will increase 18.75g.
2) If the saturation deficit is reduced 1 mb, the increase will be 6.81g.
3) If the radiation reduction is 1%, the grain reduction will be 5.47g.
4) If windbreaks increase the soil moisture by 1%, the sample grain weight will increase by 17.27g.

It should be noted here that the microclimatic effects of windbreaks come mainly from the reduction of windspeed and turbulence by windbreaks. If so, the actual implication of windspeed reduction of 1.1 m/s by windbreaks should include the effects of other microclimatic factors.

Furthermore, there are four variables in the equation. When F value was gradually increased, a surprising and interesting phenomenon happened, i.e., of the four variables, the first eliminated factor was windspeed, the second was radiation, the third saturation deficit. This means that for the crop yield the most important factor is the soil moisture while the least important is the windspeed. Initially this phenomenon seems difficult to believe. But after careful analysis, it has been shown that with the crop yield, windspeed was the first variable to be eliminated.

1) The wind effect on crop yield is indirect. The yield increase in shelter belt comes mainly from the improved microclimate by the windspeed reduction. When it does not have the physical impact and other factors are in best situation, then the changes of windspeed did not have significant effect on yield.
2) In the semi-arid and semi-moist areas, in order for crop yield to be increased further irrigation is necessary.
3) If the reduction of water in shelter belt can be looked as the relative increase of soil moisture, and thought of as the result of wind reduction by windbreaks, then the windspeed reduction by windbreaks for 1 m/s is relevant to the soil moisture increase by 1.2%.

Additionally from (1) and (2), we know when radiation is reduced by 1% in the open, the sample grain weight was reduced by 5.47 g. Therefore, considering the effect of east and west windbreaks on radiation, shading could not only be 1H distance and can be to the whole windbreak square. In practice then, if square windbreak systems are to be used, the distance between east and west windbreaks should be greater than that between south and north windbreaks, in order to reduce the shading as much as possible.

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An Evaluation Study on a Windbreak Agricultural Field

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ABSTRACT

The evaluation methodology of the agricultural effect of the field windbreak square was studied. An index of agricultural effect (E) and certain important effect indicators were established. These indicators were: the crop yield compensation year and height (Tk, Hk), the crop yield balance year and height (Tb, Hb), and the initial year and height of stable crop yield (Ts, Hs). Through the index and indicators, it is much easier to evaluate the agricultural effect of windbreaks quantitatively. This method also provides a unified way to evaluate the efforts of windbreaks with different tree species and site conditions, and establishes an important basis for the quantitative evaluation of economic benefits of windbreak planting.

Key Words *Agricultural effect, windbreak effect, shelter belt*

Introduction

The agricultural effect (AE) is the main goal and main effect of the field windbreak planting. The evaluation of AE of the field windbreaks plays a significant role in the windbreak development. Unfortunately, very little research has been done in the area of quantitative evaluation. In particular, for the windbreaks with different tree species and site conditions, there has not been a unified index, which has made it difficult to compare AE of windbreaks in different regions and with different characters. Konstantinov *et al.* (1983) suggested an evaluation method for AE of the single shelter belt. The index, however, does not seem to be very suitable for practice. A method more direct and appropriate for China has been developed for the quantitative evaluation of AE of field windbreaks.

The Evaluation Index for the Agricultural Effect of a Windbreak Square

A windbreak square (WS) is named after the four-side planting around a square crop field area (Fig. 1). Because WS can provide protection for various directions of wind, its wind reduction effect, therefore, is obviously greater than that of a single windbreak. According to Pelton (1967), Wei *et al.* (1981), Guyot (1983) and Lu *et al.* (1988), there is a negative correlation between the crop yield in shelter area and the windspeed. It can be

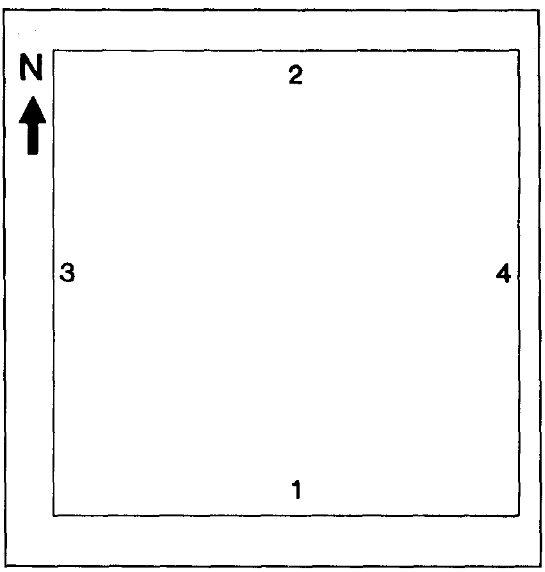

Fig. 1. *A windbreak square. 1 - 1st windbreak (primary); 2 - 2nd windbreak (primary); 3 - 3rd windbreak (secondary); 4 - 4th windbreak (secondary). Arrow - prevailing wind direction*

assumed, then, the AE of WS is greater than that of a single windbreak. Therefore, the evaluation method must be different.

Because of the improved growing conditions, the crop yield in shelter area could be higher; on the other hand, a loss of yield is caused from the crop land occupation by windbreaks. The combination of these two parts together make out an agricultural effect index.

The wind reduction of a WS is mainly from the primary windbreaks. For a single WS, if we assume the prevailing wind direction to be perpendicular to the primary windbreaks, then the protection effect of the WS is mainly by the lst windbreak. Therefore we can further assume that the crop yield increase in shelter area is mostly caused by the lst windbreak, i.e., effects of the other three windbreaks are added to the lst windbreak, then we have:

Ya, the yield increase caused by the WS

$$Y_a = L_1 \cdot D \cdot H \cdot r \cdot Y_0 \qquad (1)$$

Where L_1 is the length of the lst windbreak, D is the efficient protection distance of the lst windbreak (by the times of the height), H is the height of the lst windbreak, r is the average crop yield increase rate in the square, Y_0 is the crop yield on the exposed field (control).

The yield loss from the land occupation by windbreaks, Yb,

$$Y_b = Y_0\,(L_1W_1+L_2W_2+L_2W_2+L_3W_3+L_4W_4) \qquad (2)$$

Where L is the length, W is the width of four windbreaks. The AE of a WS is then defined as:

$$E = \frac{Y_a - Y_b}{Y_b} \qquad (3)$$

From (3), we know: if E 0, there is a negative AE, i.e., the yield increase is less than the decrease (loss); if E = 0, the yield increase compensates the yield loss from the land occupation; only if E 0, there will be a positive AE.

Introducing (1), (2) into (3), and supposing

$$S = L_1W_1+L_2W_2+L_3W_3+L_4W_4 \qquad (4)$$

then,

$$E = \frac{L_1 \cdot D \cdot H \cdot r}{S} - 1 \qquad (5)$$

The Evaluation Method for the Agricultural Effect of the Windbreak Square

For convenience, we assume: the other windbreaks do not have cumulative effects on the crops in this WS, then E in (5) is the annual AE of the WS. From the expression, we can see that the AE of a WS is related to the length and width of the windbreaks, the height and efficient protection distance of the lst windbreak, and to the mean crop yield increase rate of windbreaks.

Generally, especially for the fast-growing tree species in the plain area, the height growth curve is almost linear before the feeble period, i.e.

$$H(T) = A + BT \qquad (6)$$

Where T is time (year), A and B are parameters, which can be measured or obtained from the trunk dissection.

Introducing (6) into (5), and letting

$$F = \frac{L_1 \cdot D \cdot A \cdot r}{S} - 1 \qquad (7)$$

$$G = \frac{L_1 \cdot D \cdot B \cdot r}{S} \qquad (8)$$

Then,

$$E = F + GT \qquad (9)$$

Now it is shown, E is actually a function of time (year). When T reaches a certain year k when E = O, it is the yield compensation year (Tk), i.e., the yield increase compensates the yield loss, and the height of the lst windbreak now is called the yield compensation height (Hk).

Obviously, when E = O, there is

$$TK = -\frac{F}{G} \qquad (10)$$

If r is a constant, and we have known the efficient protection distance of the lst windbreak D, and lengths and widths of four windbreaks, we can calculate Tk by (8), (7) and (10). With (10), (6), Hk can also be obtained, i.e.

$$Hk = A - B\frac{F}{G} \qquad (11)$$

From Tk on, the annual WS caused yield increase is gradually becoming greater than the yield loss, also the cumulative yield of increase is becoming greater and greater. That is, E passes its critical point of nil and becomes greater. To a certain year of Tb, the cumulative yield of increase equals the cumulative yield of loss and the total yield now is in balance. We call Tb the yield balance year of WS. From this year on, a net yield increase will occur. The lst windbreak height now is called yield balance height (Hb).

Now we will analyse it by the cumulative agricultural effect CAE.

We have known that E changes as time (year) changes, i.e., the CAE from year O to year T can be expressed as:

$$\int_0^T E(T)DT \qquad \textbf{(12)}$$

We name it as Ec.

Introducing (9), calculating the definite integral and simplifying it, we have

$$Ec = F \bullet T + G\frac{T_2}{2} \qquad \textbf{(13)}$$

This is the expression of CAE. When N = 0, then

$$Tb = -2\frac{F}{G} \qquad \textbf{(14)}$$

As the tree height increases continuously, Ec also increases. Up to a certain year Ts, when the crops in the square are all inside the efficient protection area of the lst windbreak, Ec will not have large increases as the tree height increases. We can then assume Ec is basically in a stable state, and call the lst windbreak height at this time the initial height of stable crop yield (Hs). Naturally, Ts is named the initial year of stable crop yield, i.e., when

$$Hs = \frac{L}{D} \qquad \textbf{(15)}$$

the WS is in the initial year of stable yield. Here L is the distance between two primary windbreaks (i.e. the distance between the lst and 2nd windbreaks). From (15), (6), Ts is obtained. The AE now equals E(Ts).

When trees less in certain period (T Tm, Tm is the initial year of less growth period), (6) are no longer suitable. The H(T) is not a linear type but a progressively decreasing curve of height growth against time. For the windbreak, however, it need not be considered because the trees should assume normal growth before they go into the period.

From the above analyses, we can conclude:
when 0 T Ts, (13) is tenable;
when Ts T Tm, the CAE in a certain year Tq is

$$Ec(Tq) = Ec(Ts) + E(Ts)\,(Tq - Ts) \qquad \textbf{(16)}$$

An Example of Application of the Method to a Windbreak Square -

The site is located at Raoyang, Hebei. The WS tree species is *Populus tomentosa*. The lengths of four windbreaks are L_1 293 m, L_2 295 m, L_3 227 m, L_4 222 m respectively. The land occupation widths of four windbreaks are all 2 m. The crop was winter wheat. The tree growth curve was established by the height measurement of 30 trees with various ages.

$$H(T) = 1.45 + 1.07T$$

The coefficient is 0.990.

According to some researchers (Kang *et al.*, 1984; Lu *et al.*, 1988; Song *et al.*, 1981a, b), D is around 20 (for detailed discussion, see Cao *et al.*, 1981; Zhu, 1981), r is around 5.5 - 6.0%, 6% will be used here. Then,

$$E = -0.75 + 0.18T$$

$$Ec = -0.75T + 0.09T^2$$

When E = 0, then Tk = 4.17 - 5 (the year),
Hk = 6.80 m
When Ec = 0, then Tb = 8.33 - 9 (the year),
Hb = 11.08 m,
Hs = L/D = 11.23 m, Ts = 9.14 - 10 (the year).
Here $L = (L_1 + L_2)/2$.

From the above calculations, we know when the windbreaks reach the 5th year, it is the yield compensation year. The windbreak height is 6.80 m; when in the 9th year, it is the yield balance year, from then on, the WS offers net yield increase. The yield balance height is 11.08 m, i.e., the 10th year is the initial of stable crop yield.

If the feeble period for *Populus tomentosa* begins at the 25th year (Chinese Tree Records Editorial Board, 1976), then

$$Ec(25) = Ec(10) + E(10)\,(25\text{-}10) = 17.25$$

Ec itself is not so important, but it is a useful index when used to evaluate the agricultural effects of field windbreaks under various conditions. In combinations of the index and other three pairs of indicators, it is much easier to obtain the agricultural effect evaluation of windbreaks.

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Energy Balance, Water Use and Wheat Yield in a *Paulownia*-Wheat Intercropped Field

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ABSTRACT

As a promising agroforestry genus, Paulownia and its species have been intercropped with crops on approximately 2.0 million ha in China. A study on energy balance in different spacings of Paulownia elongata intercropping with wheat was conducted in April and May 1989 which was the 7th intercropping year. The Paulownia trees were flowering or had fully developed leaves and the winter wheat was at a stage of heading, flowering and grain filling. Results showed that the net radiation (Rn) and its components were reduced in the intercropped wheat field compared to the control plots. However, the proportion of sensible heat flux (H) to Rn was reduced, while that of the latent heat flux (LE) and soil heat flux (G) increased. The ratio of actual potential evapotranspiration and soil moisture increased, resulting in less water deficit compared to the control plots. Paulownia's effects on these parameters depend on the tree density and growth stage, and their relative distance from one another. The modified energy balance was favorable to wheat growth during its heading and flowering stage under any Paulownia spacing, but the effect on wheat growth during grain filling in denser Paulownia spacings was due to the greater reduction in Rn, perhaps brought about by the protective effects of the host tree's fully developed leaves. The intercropped wheat yield decreased in the spacings of less than 5 x 20 m but increased in those over 5 x 20 m at the 7th intercropping. A model used is suggested to predict the intercropped wheat yield. The optimum Paulownia spacing for intercropping was 5 x 30-40 m while 5 x 35 m was considered as the best.

Key words *Paulownia-wheat intercropping; energy balance; evaporation; water use; wheat yield; best model*

Introduction

Paulownia, also called China wonder tree, is a very adaptable, extremely fast-growing and multipurpose tree. It is considered as a very promising agroforestry species and extensively planted by farmers in China, particularly in the north-central plain area. To-date, about 2 million ha of farmland have been used for intercropping of *Paulownia* with wheat, corn, cotton, tea, medicinal plants and other cash crops. The common species used for inter-cropping is *Paulownia elongata* S.Y. Hu. Three major types of *Paulownia*-crop intercropping are commonly practised. In the first type (tree primary), spacing of *Paulownia* is 5 x 5-10 m with 200-400 trees per ha, where silvi culture is primary and intercropping secondary. In the second type (crop primary), spacing is 5 x 30-50 m with 40-67 trees per ha, here crops are the major products and trees are secondary. In the third type (semi-primary), the spacing of *Paulownia* is 5 x 15-25 m with 80-133 trees per ha where inter-cropping and silviculture are equally important (Zhu *et al.*, 1978; Zhu and Sastry, 1987).

The modification of the microclimate in a *Paulownia*-wheat intercropping system and its ef-

Table 1. Growth characteristics of *Paulownia* marked in different spacings

Spacings (m)	Age (yr)	Height (cm)	DBH (cm)	WE Crown Width (m)	SN Crown Width (m)	Closure*	Year observed
5 X 6	5	9.0	15.0	6.0	5.5		1986
5 X 6	8	12.0	21.7	6.3	5.7	0.87	1989
5 X 10	5	9.0	15.2	6.1	5.5		1986
5 X 10	8	12.1	25.4	6.5	5.5	0.58	1989
5 X 20	8	11.8	25.9	6.6	5.6	0.29	1989
5 X 30	12	15.0	36.0	9.0	6.0		1986
5 X 40	8	8.4	21.4	6.0	5.2	0.13	1986
5 X 50	8	8.9	21.8	5.9	5.5	0.10	1989

*Closure = crown/land area

Table 2. Locations of instruments of micro-meteorological variables collection at different growth stages of wheat in each spacing of *Paulownia*

Date	Density (m x m)	Sampling distance from west row (m)	Growth stage	
			Wheat	Paulownia
21-30 April	5 x 10, 5 x 20, 5 x 50	2, 5, 8; 2, 10, 18; 2, 13, 25	heading flowering	flowering
15-31 May	5 x 6, 5 x 10, 5 x 20 5 x 40, 5 x 50	3; 2, 5, 8; 2,10, 18 or 14; 2,11,20; 2, 13, 25	grain filling	leaves fully developed

fects on the intercrop yields have been widely studied in China (Zhu *et al.*, 1978, 1985). However, the energy balance which is an important factor associated with microclimate (Guyot, 1963; Rosenberg, 1983; Song, 1986; McNaughton, 1983; Xu, 1982), and key components in the energy and water use efficiency, and significant factors related to crop yield have not been studied in such an intercropping system (Brun *et al.*, 1984, 1985; Halverson and Kresge, 1982; Gardner *et al.*, 1981). This study attempts to delineate the modification of energy balance and water use in different systems of *Paulownia*-wheat intercropping. The effect of energy balance in different *Paulownia* spacing on wheat yield at various growth stages and combinations of both paulownia and wheat is presented to provide benchmark information on the highest economic output and/or wheat yield per unit of land.

Materials and Methods

The study was conducted at Dangshan *Paulownia* Research Station in Anhui Province. The mean annual rainfall was 773 mm with almost 80% occurring during mid June to September. Annual air temperature was 14.0°C. The soil was alluvial, sandy and alkaline. Late spring and early summer often had hot and dry winds (speeds 3 m/sec) with temperatures over 30°C and relative humidity of less than 30%. This was extremely harmful to agricultural crops, especially wheat, resulting in yield losses of 20-40%. Measurements were carried out on 24.9 ha of *Paulownia*-crop intercrop plantation with a north-south orientation. Five different *Paulownia* spacings were studied, namely 5 x 6, 5 x 10, 5 x 20, 5 x 40 and 5 x 50 m, established with 1-year old saplings in 1983. A randomised Complete Block Design (RCBD) with three replicates was used. Table 1 summarises the conditions of *Paulownia* in each spacings plantations. Each plot was between two central hedgerows, within the central replicates of the five spacings. The plot size was thus 5 x 6, 5 x 10, 5 x 20, 5 x 30, 5 x 40 and 5 x 50 m, respectively. Winter wheat was continuously intercropped yearly from tree planting. Control wheat was grown in a nearby open field. No irrigation was done.

Micro-meteorological variables collected are shown in Table 2 and Fig. 1. Each stage measurement was done hourly for three to four days with at least one day having continuous 24-hr data collec-

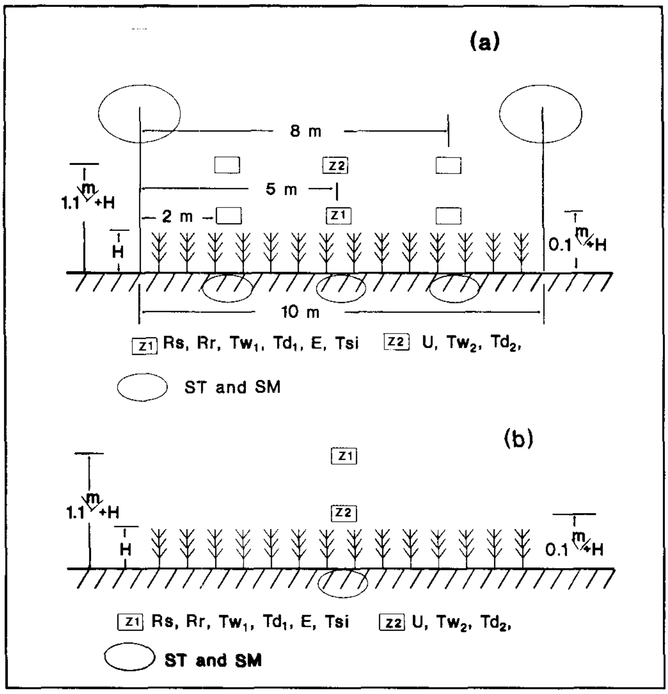

***Fig 1.** Location of micro-meteorological instruments to collect data at different growth stages of wheat and Paulownia*

tion; leaf area index of wheat, soil water content and soil bulk density were collected only once. Due to limited instruments available, parameters from spacings and control treatment were measured one after another. The incoming hourly integrated (Rs) and reflected (Rr) solar radiation over each plot was measured using Automatic Recording Radiation Stations at 10 cm above the wheat canopy layer. Wind velocity (U) was measured at 2 m height above ground with 3-cup anemometers connected to Automatic Wind Stations; dry- and wet-air temperatures (Td and Tw) were collected with ventilating wet-dry thermometers, at two levels (Z_1 and Z_2) with 1 m difference; evaporation (E) was measured by Am-3 evaporimeter. Soil temperatures (ST) were measured by curved thermometers at 0, 5, 10, 15, 20 and 40 cm depth. Maximum and

Table 3. Differences of microclimatic variables in control and *Paulownia*-wheat intercropping fields

Spacings (m x m)	T °C	Rs (%)		Rr (%)	Wd (%)	Wt (%)
	May	April	May	May	May	May
5 x 6	-2.3		-81.9	58.1	-45.2	27.9
5 x 10	-1.5	-23.2	-65.0	36.2	-58.2	31.2
5 x 20	-0.4	-25.3	-22.8	1.9	-41.6	22.2
5 x 40	0.4		- 7.6	- 1.3	-22.4	15.8
5 x 50	0.0	- 0.33	- 3.9	- 2.1	-18.7	

Note: T - temperature difference between plot and control.
Rs - decreased in total solar radiation at wheat canopy surface as percentage of the control
Rr - increased reflective radiation at wheat canopy surface as percentage of the control
Wd - decreased wind velocity in plots as of the percentage of the control at 2m height
Wt - increased percentage of soil moisture in plots than that in control as percentage.

Table 4. Variation of Rn and Rs (J $cm^{-2}day^{-1}$) in each spacing and control plots

Date	Spacings (m x m)	Growth stages		Intercropped			Control			RN* (%)
		Paulownia	Wheat	Rs	Rn	Rn/Rs (%)	Rn	Rs	Rn/Rs (%)	
29-30 May	5 x 6	leaves	554.0	554.0	101.0	18.2	2793.2	2232.0	75.1	4.5
26-28 April	5 x 10	flowering	1487.4	1487.4	1041.8	70.0	1923.6	1393.0	72.4	74.8
22-25 May	5 x 10	leaves	1184.0	1184.0	790.9	66.8	2808.4	2117.6	75.4	28.1
21-23 April	5 x 20	flowering	1441.2	1441.2	1017.6	70.6	1890.9	1393.2	73.6	73.0
15-18 May	5 x 20	leaves	2410.1	2410.1	1738.4	73.5	3118.9	2293.1	72.1	75.8
26-28 May	5 x 40	leaves	2775.0	2755.0	2225.3	74.9	3226.0	2416.3	74.9	92.1
28-30 April	5 x 50	flowering	1439.9	1439.9	1044.3	72.5	1485.5	1083.1	72.9	96.4
19-21 May	5 x 50	leaves	2141.4	2141.4	1693.8	79.1	2167.1	1722.5	79.4	98.3

Note: indicates the percentage of Rn in the intercropped over that in control

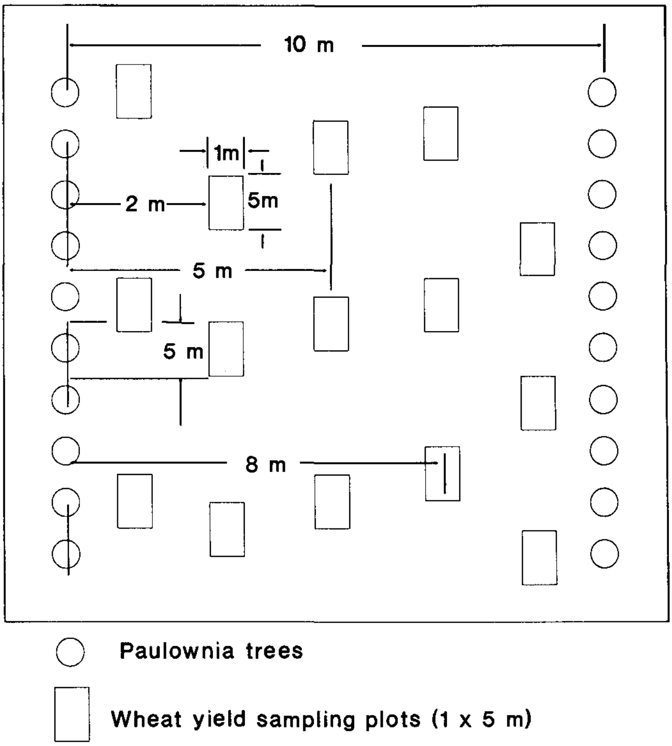

Fig 2. Wheat sampling plots in the 5 x 10m Paulownia spacing

minimum soil surface temperatures were measured by the maximum and minimum thermometers. The soil moisture (Sm) was measured by gravimetric sampling method with 10 cm as a layer within 0-40 cm beneath the soil surface. The Bowen-Ratio Energy Balance (BREB) method was used for hourly calculation of actual evapotranspiration (ETa) and the Penman method for the daily calculation of potential evapotranspiration (ETp) as described by Xu (1982).

Wheat yields were determined from 1 x 5 m plots established along transects that run parallel to the *Paulownia* at every other specified distance (n m) from the west *Paulownia* hedgerow (Fig. 2). The RCBD with three replicates method was used in each sampling strip. The distance n between the transect varied from 1-3 m from the close and near-to-tree and from 5-10 m for the widest spacings. In the control plots 15 samples were taken.

The data collected included leaf area index, productive tillers, spike length, filled spikelets/spikes and 1,000-grain weight, grain yield was calculated as:

$$Yd = \sum_{j=1}^{n_d} \frac{Y_d \cdot j \cdot L_d \cdot j}{L_d} = \sum_{j=1}^{n_d} L_d \cdot \frac{Y_d \cdot j \cdot i/3}{W_d}$$

whereY = wheat yield (kg/ha); d = *Paulownia* density; j = strip or transect number; L = represented width; W = width between rows of *Paulownia*; i = sample number (3 samples per strip).

Results and Discussion

The microclimate was modified in the intercropped plots compared to that in the control. The comparison of means of microclimatic variables in intercropped plots with those in control is presented in Table 3. These exchanges affected the variation of energy balance and the wheat yield. The greater changes were observed under the denser stand. In April, when the *Paulownia* canopy was not yet well-developed, changes were less than in May, and only under the 5 x 6 and 5 x 10 m stands could significant differences be found versus those in the control plots.

Energy Balance -

Total net radiation (Rn) was significantly reduced in the 5 x 6, 5 x 10 and 5 x 20 m spacings as compared with the open field but approximately the same in 5 x 40-50 m compared with that in the open during May, and much less affected by the canopy during April. *Paulownia*'s effect on the rate of total Rn to solar radiation (Rn/Rs%) in intercropped areas was negligible during both stages, except in the 5 x 6 m spacing (Table 4).

Most energy was consumed in latent heat flux (LE) both in open and intercropped plots, although the ratio of LE to Rn under most circumstances in the intercropped plots was greater than that in the open. Sensible heat flux (H) oscillated considerably both in the intercropped area and in the open. In most cases, however, H was reduced in the intercropped plots compared with that in the control. Soil heat flux (G) was small in proportion to Rn both in intercropped and open plots. It was generally higher in intercropped areas, especially in denser spacings due to the higher water content of the soil. The changes in energy balance at the middle of each spacing on typical days demonstrated that denser the spacings the lower the Rn, LE and H, but the greater the proportion of energy consumed in LE, G and less in H compared

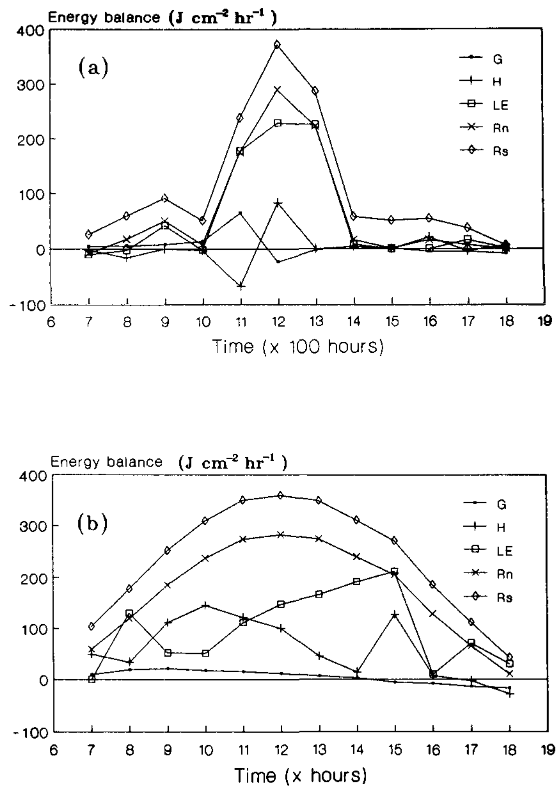

Fig 3. Hourly distribution of energy components over a day in 5 x 10m Paulownia intercropping (a) and control (b) on 23 May 1989

with that in open plots (Table 5).

The distribution of Rn with Rs and its components varied with time throughout the day (Figs. 3a, b and 4). Rn and each of its components were very low in the early morning and late afternoon in 5 x 10 m (Fig. 3a) due to the reducing effect of *Paulownia* shading on radiation. Most energy was gained between 10 am and 2 pm. LE increased with incoming energy, especially during 10-11 am and 1-3 pm periods. The peak of LE coincided with that of Rn but the proportion of LE to Rn decreased towards this point because of the limited soil water supply and/or an increased stomatal resistance. The H values were negative at 11 am and a similar situation occurred at 10 am at 1 pm and 2 pm at 14 m in 5 x 20 m (Fig. 4a, c). This may be due to the occurrence of temperature inversion or of stable conditions under shading, resulting in a higher temperature in the upper layers than in the lower ones because of the *Paulownia* canopy serving as a barrier to the air mixing. Also higher temperature could exist in the crowns. Therefore, the energy exchange was from the higher air layers to the ground, and it was one hour ahead of G.

Rs and Rn were considerable at most times during the day in large spacings such as that in the 5 x 20 and 5 x 40 m plots. The fraction to each component was less affected compared with that in the 5 x 10 m and open plots, except for the sensible heat flux that obviously decreased and stabilised (Fig. 4). The pattern of energy exchange at different distances from the tree hedgerows varied with time. Fluctuations in all variables were larger in the strips further from the tree-rows, also the absolute value of variables increased with the distance from the row.

At night, Rn and G usually were zero and/or negative, H was positive and LE unstable. The highest H appeared in the middle, between the tree rows because of the reducing effect on air mixing of the tree barrier. Thus the temperature gradient was more negative near the tree but less in the middle; LE values were negative and dew formed. Moreover, dew was rarely found under the tree crown but more often towards the middle between tree rows.

Evapotranspiration -

Both actual evapotranspiration (ETa) and potential evapotranspiration (ETp) decreased in any spacing of intercropping during clear days. The denser the spacing, the greater was the reduction in ETa (Table 6).

Paulownia had greater effects in reducing ETa in denser spacing after the leaves were fully developed than that during the flowering stage (Table 6). Its reduction in spacings of more than 5 x 20 m, however, can be considered as negligible in both stages of wheat. ETa could be higher during cloudy weather in the intercropped area than in the open (Table 6). ETa varied with the distance from *Paulownia* rows with the highest ETa at the middle between two rows of *Paulownia* (Fig. 5). *Paulownia* trees minimised the relative water deficit (Dw) in the intercropped zones since ETa was less reduced than ETp, especially during wheat heading stage. At higher tree densities, lower relative water deficits were detected (Table 6). This may be explained by a reduction in driving force for ET, and in addition, an increased leaf diffusion resistance caused by shading. In the large spacing, however, the slight reduction on Rn was sufficient for providing energy for Eta, such that the wheat could be constantly supplied by soil water.

Table 5. Comparison of energy balance (J $cm^{-2}day^{-1}$) in different Paulownia spacings (m x m) and control

Date	Spacings	G	H	LE	RN	G/Rn %	H/Rn %	LE/Rn%	Weather
29 May	5 x 6	35.6	-42.7	108.0	101.0	35.2	-42.2	107.0	fine
	Control	54.2	1150.0	1027.7	2232.0	2.4	51.5	46.0	
27 April	5 x 10		139.8	922.9	1066.5	0.4	13.1	86.5	cloudy
	control	7.1	818.1	613.5	1438.7	0.5	56.9	42.6	
23 May	5 x 10	32.5	74.4	666.3	773.2	4.2	9.6	86.2	fine
	control	46.4	730.4	1822.4	2598.2	1.8	28.1	70.1	
23 April	5 x 20	61.7	2.2	884.2	947.9	6.5	0.2	93.3	cloudy &
	control	54.5	210.6	1075.7	1340.7	4.1	15.7	80.2	after rain
15 May	5 x 20	30.0	167.6	1107.2	1304.8	2.3	12.9	84.9	fine
	control	36.8	219.5	1453.2	1709.5	2.2	12.8	85.0	
27 May	5 x 40	79.1	283.4	1755.8	2118.3	3.7	15.4	80.9	
	control	62.6	205.6	2067.1	2335.3	2.7	8.8	88.5	
29 April	5 x 50	23.6	248.1	532.6	1044.3	2.3	38.0	59.7	cloudy
	control	16.5	480.0	586.3	1083.1	1.9	46.1	52.0	
21 May	5 x 50	16.0	558.6	941.7	1516.4	1.2	38.4	60.7	fine
	control	29.8	770.2	753.6	1553.7	2.0	47.2	50.7	

Table 6. Actual and potential evapotranspiration (mm day^{-1}) in 8-year old *Paulownia* trees under different spacings and control plots

Date	Spacings (m x m)	Growth Stage		ETa[a]			ETp[b]		Dw (%)[c]	
		Paulownia	Wheat	D/2[d]	CK[e]	<CK %	D/2	CK	D/2	CK
29-30 May	5 x 6	leaves	filling	0.43*	4.11	89.5	0.50*	18.85	14.0	78.2
26-28 April	5 x 10	flowering	heading	3.31	3.98	16.8	5.53	7.45	40.1	46.6
22-25 May	5 x 10	leaves	filling	1.54	6.97	77.9	4.30*	16.29	64.2	57.2
21-25 April	5 x 20	flowering	heading	3.61	4.49	19.6	4.68*	14.69	22.9	69.4
15-18 May	5 x 20	leaves	filling	3.44	5.41	36.4	13.03	13.82	73.6	60.9
26-28 May	5 x 40	leaves	filling	7.34	7.96	7.8	15.4	17.34	52.3	54.1
28-30 April	5 x 50	flowering	flowering	3.28	3.68	10.9	3.76	4.45	12.8	17.3
20-21 May	5 x 50	leaves	filling	2.84	3.09	8.1	7.68	9.89	63.3	68.8

a - actual evapotranspiration
b - potential evapotranspiration
c - relative water deficit
d - at the middle of two tree rows
e - control plots
* - indicate significantly reduced compared to that in control

Evaporation -

There was greater reduction of evaporation (E) in intercropped fields than that in control plots. The denser the spacing, the higher the reduction of E (Table 7). The reduction in E was greater than in ET especially at denser tree spacings. At night E was very low both in the intercropped and control plots and no systematic difference between the treatments could be found. Thus, at denser spacings, a larger proportion of water was used for transpiration than for evaporation.

The Intercropped Wheat Yield -

The intercropped wheat yield increased with decreased spacing (Table 8). With each spacing, wheat yield was highly correlated with distances from the westernmost rows, according to Yp = a + bx + cx (Table 9). A prediction for the average wheat yield in each spacing thus can be formulated as:

$$Y_{ap} = A + \frac{BL^2}{2} + \frac{CL^3}{3}$$

where Y_{ap} = predicted average yield in a given spacing, A, B and C, meant the constants in Table 9 for a given spacing, L = the total length between two tree rows in a given spacing, at an intra-row

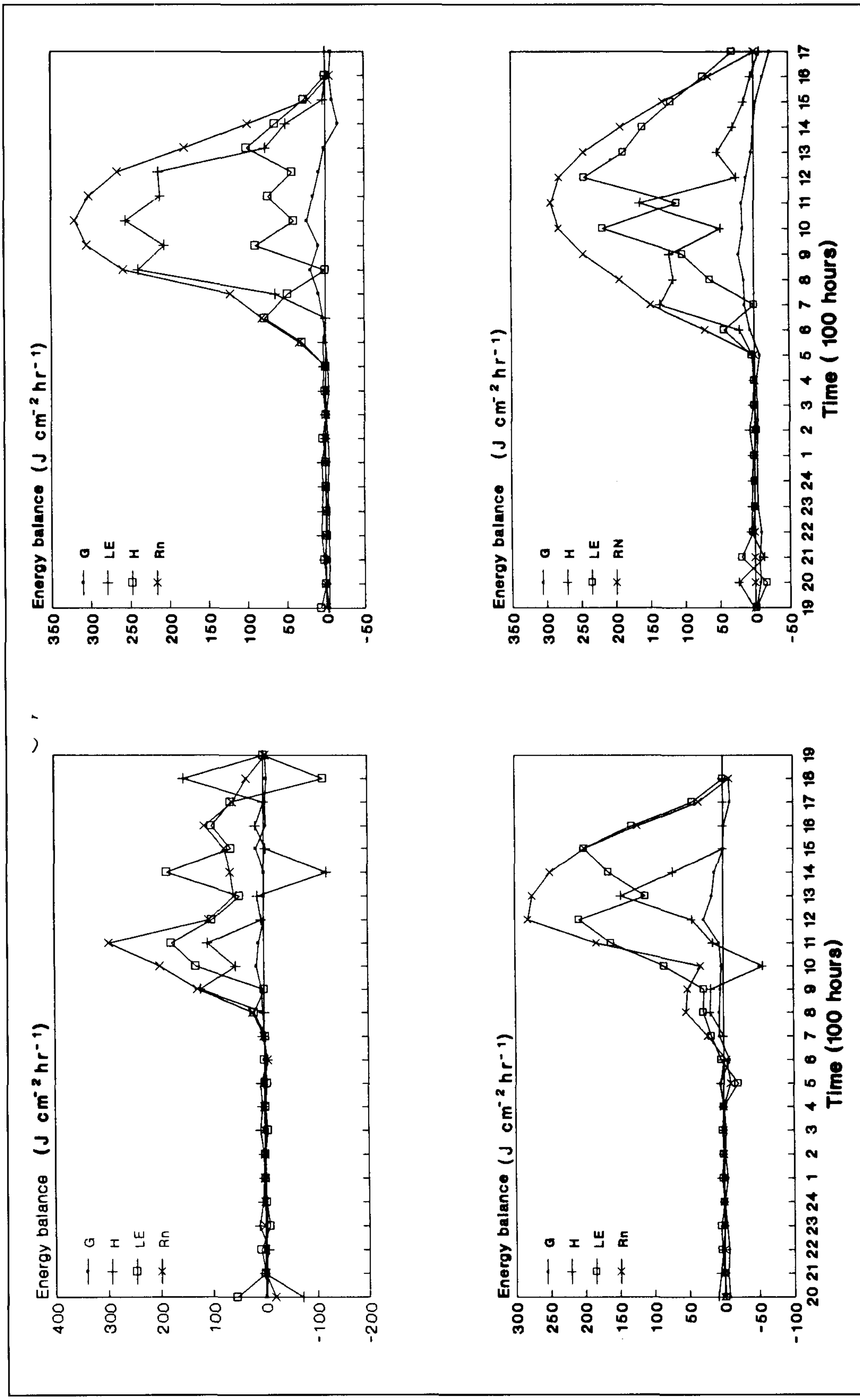

Fig. 4 *Hourly distribution of energy components over a day at 2m (a), 10m (b) and 14m (c) in the 5 x 20m Paulownia intercropping and control (d) on 18 May 1989.*

Table 7. Evaporation rate (mm day^{-1}) in the intercropped and control plots in April and May 1989

Date	Spacings (m x m)	Distances from west tree row (m)									Control	Weather
		2	5	8	10	11	13	18	20	25		
30 May	5 x 6	2.7									7.4	fine
30 May	5 x 6*	0.2									0.2	
31 May	5 x 6*	0.1									1.4	
26 April	5 x 10	2.2	2.6	2.3							6.7	fine
27 April	5 x 10	2.4	3.1	2.3							6.4	fine
28 April	5 x 10*	1.2	1.1	1.5							2.7	
22 April	5 x 20	1.3			1.5			2.0			1.4	cloudy
15 May	5 x 20	1.8			2.5			1.8			3.2	fine
16 May	5 x 20	2.3			3.5			2.5			4.2	fine
16 May	5 x 20	0.2			0.5			0.2			0.3	
17 May	5 x 20	2.1			4.3			2.9			4.9	fine
26 May	5 x 40	3.7				4.75			4.7		6.3	fine
28 May	5 x 40	2.55				3.6			3.4		4.4	fine
30 April	5 x 50	2.8					3.5			3.5	3.2	fine
21 May	5 x 50	1.6					2.1			1.9	3.1	fine

* at night

Table 8 Average wheat yield (kg ha^{-1}) with various spacings of Paulownia and control plots

Spacings (m x m)	Number of samples	Average yield
5 x 6	5	1,507.28 a*
5 x 10	9	1,866.85 b
5 x 20	19	2,649.85 c
5 x 40	39	3,109.55 e
5 x 50	49	3,261.15 f
open	11	2,904.77 d

* - different letters indicate significant difference at $P \leq 0.05$

Table 9. Regression equations for wheat yield (kg ha^{-1}) with distance in each *Paulownia* spacing

Spacings (m x m)	Predicted Yield		Constants A B C	R2 (Adj.)	Significance level
5 x 6	$Yp_6{}^a$	=	$1173.75 + 164.66D - 14.89D^2$	0.84	*
5 x 10	Yp_{10}	=	$2146.76 - 142.88D + 13.72D^{2b}$	0.94	*
5 x 20	Yp_{20}	=	$2336.42 + 116.39D - 6.54D^2$	0.83	*
5 x 40	Yp_{40}	=	$2100.11 + 149.92D - 3.84D^2$	0.90	*
5 x 50	Yp_{50}	=	$2598.47 + 74.37D - 1.45D^2$	0.56	*

a - $Yp_{(6,\ 10,\ 20,\ 40\ and\ 50)}$ = predicted intercropped wheat yield in the 5 x 6, 5 x 10, 5 x 20, 5 x 40 and 5 x 50 m Paulownia spacings, respectively.
b - D presents the distance (m) from west Paulownia row

Table 10. Correlation coefficient (r2) of linear regression of wheat yield with Rn, H, LE, ETp, Dw during heading and filling stages of wheat growth

Stages	RN	RN/RS %	H	ETa	ETp	Dw
heading	-0.397	0.746	-0.214	0.083	-0.555	-0.483
filling	0.890*	0.751	0.742	0.770	0.819	0.580

* indicates significantly related ($P \leq 0.05$)

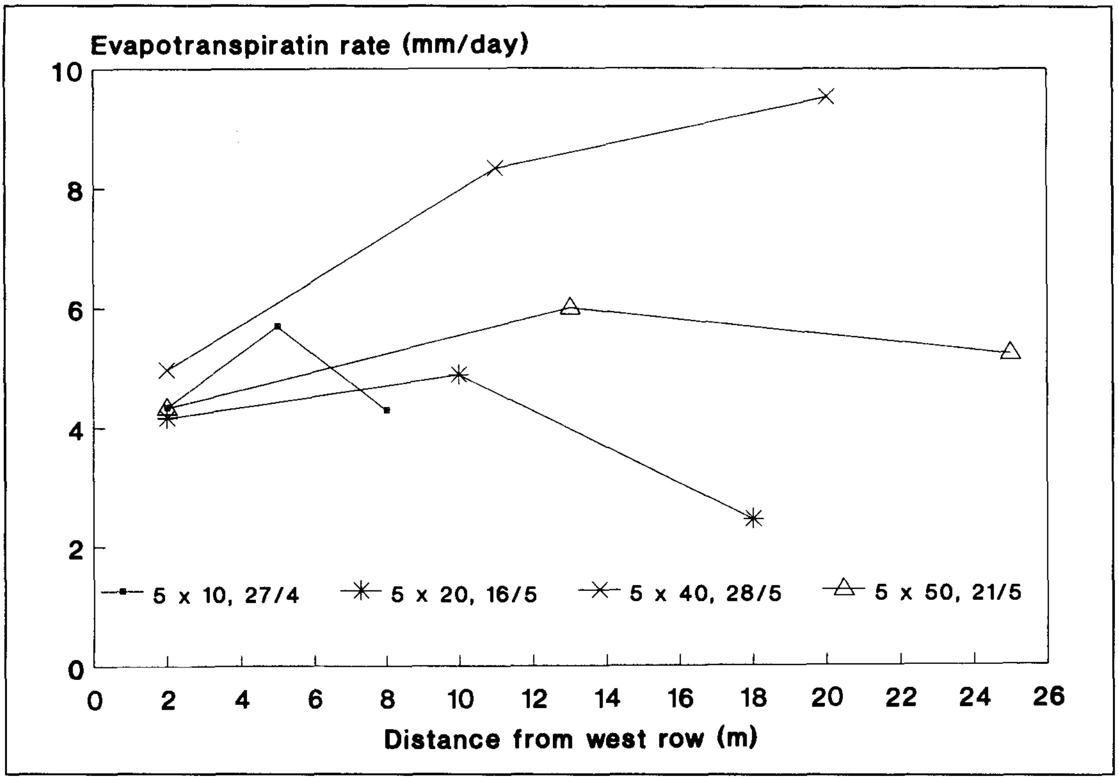

Fig 5. Actual evapotranspiration at different distances from Paulownia rows in different spacings on 27 April and 15, 28, 21 May 1989

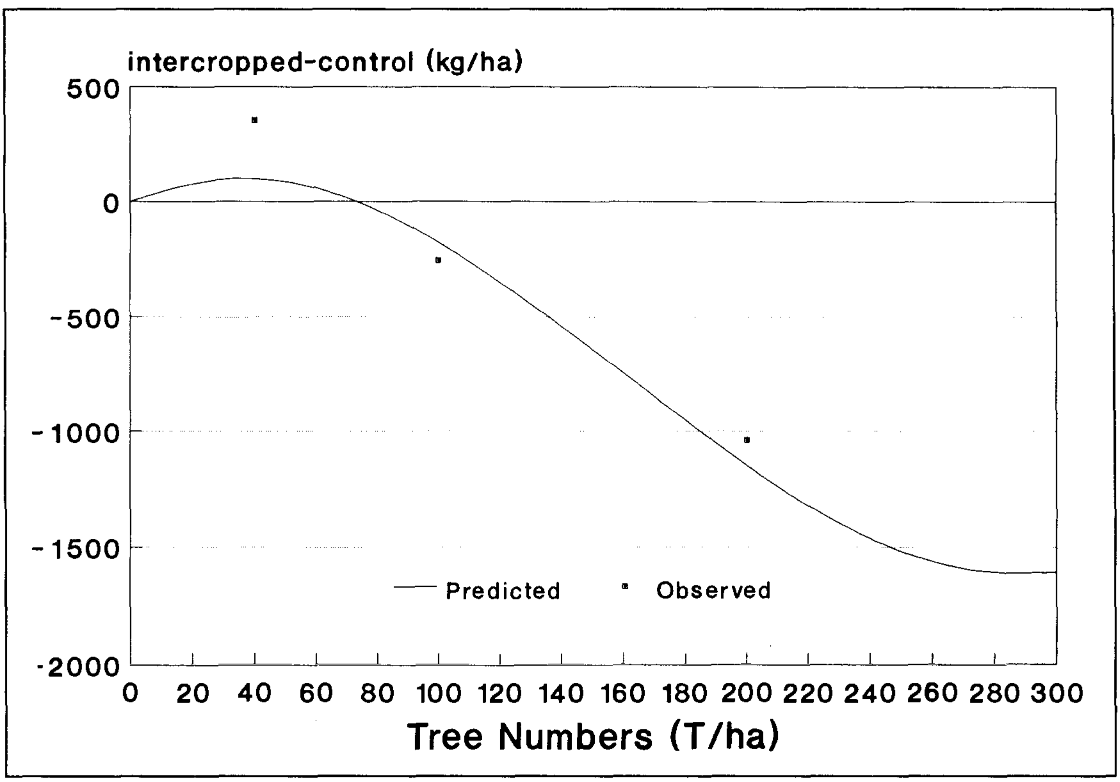

***Fig 6.** Predicted model of wheat yield difference (intercropped - control) for different Paulownia spacings at the 7th intercropping year*

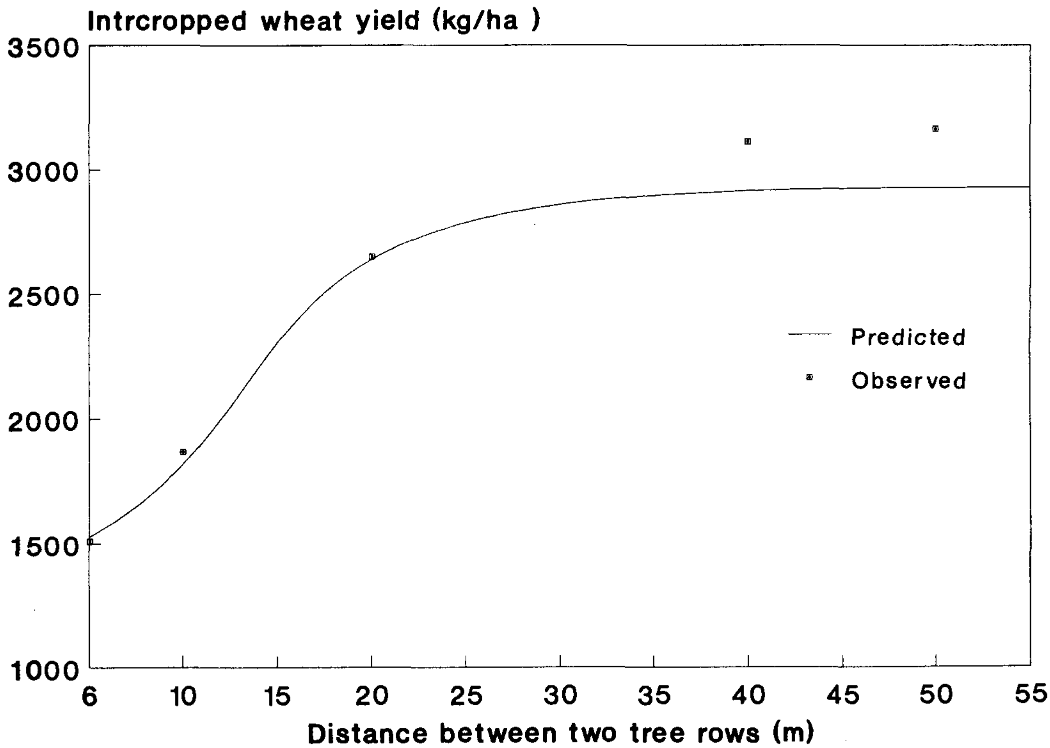

Fig 7. Predicted model for average intercropped wheat yields in the different Paulownia spacings at the 7th intercropping year

tree distance of 5 m.

The Correlations of Intercropped Wheat Yield with Energy Balance -

Several components of the energy balance were closely correlated with the intercropped wheat yield especially during the grain filling phase of wheat (Table 10). Apparently growing conditions during wheat heading and flowering were much less important for determining grain yield than those during grain filling. During the former stage the main factors affecting wheat yield were ETp and relative water deficit (Dw), which were negatively related to the yield. Dw was positively related with H (r = -.617) and wheat in non-irrigated areas before or at wheat heading and while *Paulownia* is flowering.

At grain filling, the wheat yield was positively related with all the factors because Rn is the driving force of other factors such as H, LE, and ETp (with r = 0.75, 0.91 and 0.98, respectively), indicating that the energy was the main limiting factor. ETp was the next important factor related to wheat yield during wheat grain filling as suggested by the negative impact of *Paulownia* on this parameter. Increasing solar radiation increased transpiration and photosynthesis and finally the wheat yield. Wheat yield was positively correlated to D because D was determined by ETa and ETp, while D was more related to ETp (r = 0.61) than to ETa (r = 0.378) so that increasing ETp increased D. Generally, it may be said that the effect of decreased energy during the wheat grain filling stage is greater than the increased ETa/ETp on the increasing wheat yield during the heading and flowering stages in denser *Paulownia* spacings.

Establishing the Intercropped Wheat Yield Model -

As wheat yield is a function of tree density and distance from the tree fitting Yap = a + bx + cx, it can be said that the average yield at 2-4 m, D/4 and D/2 (D = the distance between two tree rows) from the tree is accurate enough to present the average intercropped wheat yield in most spacings especially the denser ones. Three samples were randomly selected in each spacing to establish the model. The combined equation for intercropped yield in a given distance from the tree in a given density was generated as:

$$Y_p = Y_1 + Y_2$$

where Yp = predicted yield as a function of distance from the tree and tree density, Y1 = observed yield at D m in N density + (average yield in open - average yield in N density) + average observed yield in the control plot, Y2 = difference of average wheat yield between the intercropped in N density in control plots,

$$Y1 = 2137.2 + 1.95ND - 10.25 \times 10^{-4}N^2D^2$$

$$Y2 = 78.7 + 6.77N - 0.107N^2 + 2.22 \times 10^{-4}N^3$$

here N = number of trees per ha
D = distance from western tree row (m).

Hence the average intercropped wheat yield in density N (tree per ha) was given as:

$$Yp = 2215.83 + (1.95D + 6.77)N - (10.25 \times 10^{-4}D^2 + 1.07)N^2 + 2.22 \times 10^{-4}B^3$$

The average yield in each spacing is

$$Y_{ap} = \frac{1}{N} \times Ypd(D)$$

Fig. 6 shows the predicted yield difference between the intercropped and control plots based on equation 5, indicating that the wheat yield difference was very sensitive to the tree density of 80-160 trees per hectare or 25-14 m tree spacings at 5 m distance intra-row. The absolute yield difference linearly increased with the number of trees, with approximately 410 kg/ha/m decrease of width (at 5 m distance intra-row). The yield could be stabilised at 280 trees per ha or 7 m width at an intra-row distance of 5 m. The yield difference between the intercropped and control was greater at a 33 m row distance or 60 trees per ha. The predicted average yield at the different densities is presented in Fig. 7 and the curve varies very steeply from 5 x 6 to 5 x 15 m, the rate of increase gradually drops with increasing distance between rows, with a stable yield level being reached from 30-40 m.

The determination of the best model should be based on the objectives of intercropping. The most common objective in the study area is to increase wheat yield and at the same time obtain the maximum gain from the *Paulownia* trees. The 5 x 30 to 5 x 40 m spacing range was considered suitable, with the 5 x 35 m the optimal tree density at the 7th year of intercropping for the primary crop. Compared with the observed data, the model is most accurate at 5 x 20 m and valid only within the range of observed densities.

Conclusion

The extent and amount of the effects of *Paulownia* on intercropped wheat can be explained by the tree's physical and physiological influences on modifying the microclimate and energy balance regime in the plant environment. Energy balance in the intercropped area varies with space and time, and the difference in energy behaviour between the intercropped zone and the open field accounts for the differences in yield of associated crops. Energy balance pattern within the intercropped area shows that energy balance varies with the time of day, distance between trees, *Paulownia* density and growth stage. The variation explains the discrepancy of crop yield in the intercropped zone in a given frame and space. Intercropping trees to increase wheat yield is desirable from the view of increasing energy use efficiency. Negative effects of *Paulownia* result from shading, especially in dense spacings of *Paulownia* during the wheat grain filling stage.

When aiming for maximum wheat yields, and at the same time wanting to grow more trees, the spacing range of 5 x 30 to 5 x 40 m is considered suitable, with 5 x 35 m as the optimal *Paulownia* density at the 7th year of intercropping. In addition, the following suggestions should prove useful:

1) Thinning should be done in 5 x 6-20 m spacing using selective methods by removing rows of trees so that the width between two rows is doubled.
2) A suitable *Paulownia*-wheat intercropping pattern could be to plant trees with 5 x 5-10 m, then have a selective thinning every other row in the 4th year. At the 7th year, thinning again in the same way would result in 5 x 20-40 m spacings. At the same time replenishment with young trees on the clear cut rows could keep the *Paulownia* more productive, protective and the whole system sustainable.
3) Irrigation should be done before and/or during heading and flowering stages of the wheat.

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Solar Radiation Distribution in Intercropped Fields With Paulownia

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ABSTRACT

Based on field observations and following the geometric properties of Paulownia canopy, and principle of solar radiation transfer inside the canopy, various patterns of solar radiation distribution are simulated and the tree shade shift in Paulownia intercropping fields. Results show that the distance of tree rows in an optimum Paulownia inter-cropping system varies from 10-40 m with the ages when the distance between trees is 5 m. It is also indicated that best profits can be obtained from Paulownia intercropping system after seven years of intercropping with the row spacing of 40 m.

Key words *Optimal structure of Paulownia intercropping; solar radiation intensity; sun's elevation angle; leaf-area density*

Introduction

As an useful ecological system to promote the productivity of land, PCI has been adopted extensively as a new farming system in Huang Huai Hai Plain. However, further improvement on PCI is needed to promote greater yield increase. The *Paulownia* planting promotes favourable microclimate in favour of crop growth (Lu, 1981). The shading effect of trees decreases solar radiation intensity, creating an adverse influence on crops. The solar radiation distribution patterns inside the PCI system is the major basis for understanding the principle of the yield patterns and constructing a model for optimal structure.

Recently some studies have been documented concerning the shading of field windbreaks and PCI system together with their effect on crop growth and development (Liu, 1988, 1989). They are mainly based on light intensity measurements. Also, a remarkable advance has been made in the theory of radiation transfer within canopies (Cui and Zhu, 1986; Liu, 1987; Liu and Zhang, 1985) which helps to construct a model based on the geometry of *Paulownia* canopy at various stages of growth, its biological properties and principles of radiation transfer distribution in open field. By inferring radiation characteristics in a variety of structures of PCI system and with the help of a model, one can know space-time pattern of radiation in a field of a given PCI structure at any location and its relation to crop field in terms of a few parameters of significance.

Methods and Observations

The present study was carried out on the basis of vast quantity of field observations and measurements to prepare a model on computer, which was put into operation after the favourable comparison of its theoretical results to the measurements. Dangshan *Paulownia* Station (34°18'N, 116°24'E) was selected for experiment in various structures of PCI fields. Observations were done from 20 April through 4 June 1989. In the experimental plots, *Paulownia* trees were planted at S-N orientation with planting spacings of 5 x 6, 5 x 10, 5 x 20, 5 x 40 and 5 x 50 m. The observations were also carried out in open field as control. During the observation the field was covered with winter wheat (SXW 7859 variety). Multi-sensory equipment (made by Cimel Co.) was used for general and reflected radiation, which can automatically show the instantaneous values at the hour and the accumulated ones over the interval. The measuring points were located at 2, 10 or 11, 18 or 20 m away

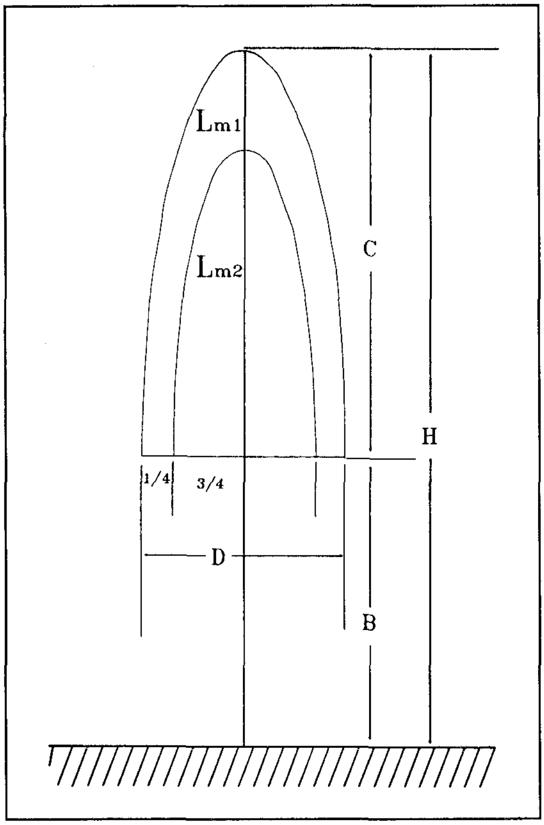

Fig. 1 Schematic view of the long-section of leaf canopy of a Paulownia tree

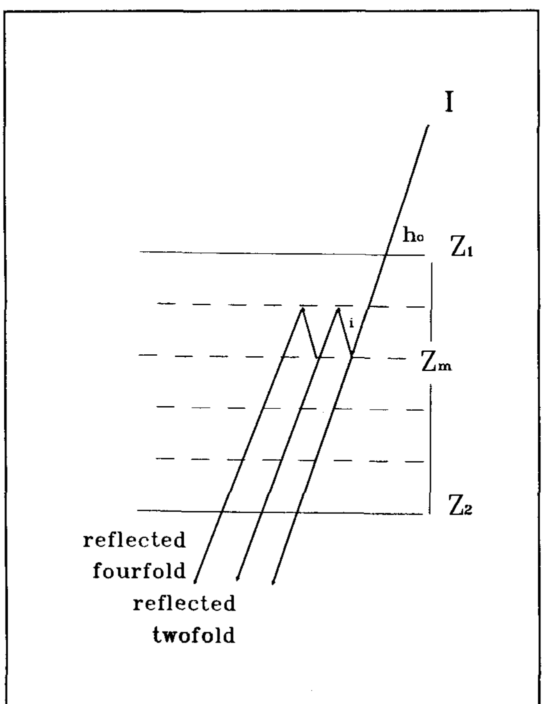

Fig. 2 Light travelling inside the leaf layers

from the tree row on the west side. Meanwhile, total height, trunk height and crown diameter of *Paulownia* trees were also measured and the tree canopy structure estimated. Leaves in the 1/4 semi-ellipsoid of the canopy were all taken to figure out the leaf area by weighing for the density.

Major considerations involved in the inference with the aid of radiation simulation theory are as follows:

Geometry of the Canopy -

The canopy of a single *Paulownia* tree can be visualised as a semi-ellipse when it is observed from distance. The side branches within the canopy stretch out mainly at 80-90^{o} angle from the trunk, and only with a few twigs inside. *Paulownia* trees are light-loving and leaves are large and sparse, having over 150 cm in area of a single mature leaf, and 83% of the leaves spread nearly horizontally. For this reason, the canopy was assumed to be semi-ellipsoid with leaves distributed horizontally.

Paulownia has much of their leaves at the upper part of the branch, there are only a few leaves growing in the lower 3/4 portion. In contrast to other tree species with stratification in canopy, *Paulownia* has distinct outer or photosynthetic, layer and inner supporting layer of leaves. The outer layer is less thick but three-fold heavier in leaf density. On this basis, the geometry of the canopy structure can be divided simply into two layers of leaf density. Fig. 1 is a vertical cross-section of the canopy in the form of a set of concentric semi-ellipses with the major and minor axes of the inner being 3/4 of that of the outer, respectively. We assume L_{m1} and L_{m2} to be the leaf-area density for the outer and inner layers, respectively. Following the earlier statement, we have

$$L_{m1} = 3 \times L_{m2} \quad (1)$$

For small stand spacing, the neighbouring trees have their canopies cross each other more heavily as they grow, resulting in a tree fence and the light demand of leaves causes the semi-ellipsoid structure to get thick at the outer and thinner at the inner layer at the crossed part but the cross-section perpendicular to the canopies. The tree belt remains unchanged in form. The 5-year old *Paulownia* trees are found to be closed altogether in canopies and the 6-year old trees can be viewed as uniform in the canopy fence. Therefore, the radiation pattern is considered only at different distances from the tree belt.

Table 1. Time variation of PR and PT (%) measured on 18 July 1989.

(BST) time (hr)	9	10	11	12	13	14
PR	25.2	20.0	19.2	17.4	--	19.0
PT	20.6	17.0	--	12.4	14.2	16.0

Effect of the Canopy on Solar Radiation -

For a layer of leaves uniformly distributed the reducing rate of direct solar radiation is proportional to the transmittance of leaves, radiation intensity, and the number of leaf layers. Assuming I to be the intensity of incident ray, LM to be the leaf-area density and Z the thickness of leaves evenly distributed, we have

$$dI = -(a+b)\ I \cdot dn \qquad (2)$$

$$dn = LM \cdot dz \qquad (3)$$

$$a + b + c = 1 \qquad (4)$$

where a, b and c are the reflection, absorption and transmittance coefficient, respectively.

After integration we find

$$I = I_o \cdot e^{-(a+b)\ LM \cdot Z} \qquad (5)$$

in which I_o is the intensity of rays before entering the canopy.

Light travelling through leaves is complicated. A part of the reflected light may repeat the process of reflection, absorption and transmittance through the leaves, resulting in a limited amount of radiation returning to the air. Thus, it is necessary to put part of reflected light into the total radiation received by the leaf layer below. If the leaf is assumed in horizontal position, then part of light will be in the same direction as the incident ray after reflection two, four, six times (see Fig. 2). In other words, part of light reaches the ground in the end after an even number of reflection. Letting P be the radiation striking the ground through the leaf and Z_m be the thickness of the layer, we have

$$d\Delta P = I_o \cdot e^{-(a+b)\ LM \cdot Z} (a2 + a4 + ...) \cdot e^{-(a+b)\ LM\ (Zm-Z)}$$

$$\Delta P = \int_{Z_1}^{Z_2} \cdot I_o \cdot e^{-(a+b)\ LM \cdot Z_m} \cdot [\lim_{n \to \infty} \frac{a^2(1-a^{2n})}{1-a^2}] \cdot dz$$

so that

$$\Delta P = I_o \cdot e^{-(a+b)\ LM \cdot Z_m} \cdot \frac{a2 \cdot LM \cdot Z_m}{1-a^2} \qquad (6)$$

Table 2. Insolation hours at various distances from the tree belts in a field of PCI in contrast to 13.00 in an open field, on 24 April 1989.

Distance from tree belt (m)	Spacing between tree belts (m)			
	20	30	40	50
0	1.8	2.7	3.3	3.3
0.5	1.7	2.7	3.4	3.4
1.0	1.7	2.8	3.4	3.4
1.5	1.8	2.8	3.6	3.6
2.0	2.0	3.0	3.6	3.6
2.5	2.3	3.2	4.1	4.1
3.0	2.5	3.4	4.3	4.3
3.5	2.8	3.7	4.7	4.7
4.0	3.1	4.0	5.1	5.1
4.5	3.1	4.6	5.5	5.5
5.0	3.8	5.0	5.8	5.8
5.5	4.2	5.3	6.3	6.3
6.0	4.5	5.7	6.8	6.8
6.5	4.8	5.9	7.2	7.2
7.0	5.0	6.3	7.3	7.3
7.5	5.2	6.6	7.5	7.5
8.0	5.3	6.8	7.7	7.7
8.5	5.3	7.0	7.8	7.8
9.0	5.4	7.2	8.0	8.0
9.5	5.4	7.3	8.0	8.0
10.0	5.4	7.4	8.2	8.3
11.0		7.6	8.5	8.6
12.0		7.7	8.7	8.9
13.0		7.7	8.8	9.1
14.0		7.9	9.0	9.3
15.0		8.0	9.2	9.6
16.0			9.2	9.6
17.0			9.3	9.9
18.0			9.3	10.2
19.0			9.4	10.2
20.0			9.5	10.2
21.0				10.2
22.0				10.2
23.0				10.3
24.0				10.3
25.0				10.4

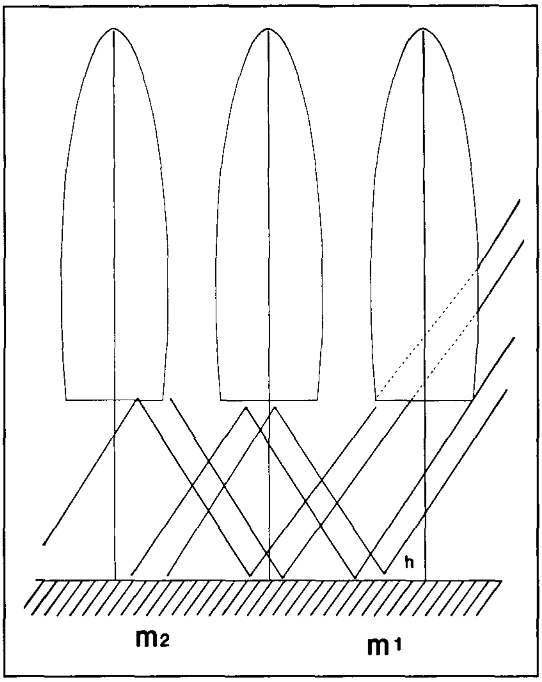

Fig. 3 Rays travelling inside the canopy

Similarly, the reflected radiation can be derived that escapes from the layer across Z_m of the form

$$I_u = \frac{a}{1-a_2} \cdot \frac{I_o}{2(a+b)} \cdot (1-e^{-2(a+b)\,LM\cdot Z_m}) \qquad (7)$$

It follows that if the ray passes through two leaf layers with different densities (given L_{m1} and L_{m2} to be the leaf-area density, Z_1 and Z_2 to be the thickness of leaf layer, respectively of upper layer and lower layer), part of radiation that has reached the layer of L_{m2} will go back to the layer of L_{m1} after multiple reflection, and part of the remaining radiation goes through multiple reflection in the layer of L_{m1} and re-enters the layer of L_{m2}. If the upward reflection radiation from L_{m2} is I_u, has the form

$$I_u = I_o \frac{1-a^2+a^2\cdot L_{m1}\cdot Z_1}{1-a^2} \cdot e^{-(a+b)\,L_{m1}\cdot Z_1}$$

$$\frac{a^2}{2(1-a^2)(a+b)} (1 - e^{-2(a+b)\,L_{m2}\cdot Z_2})$$

then the total radiation downward from L_{m1} should be

$$I = I_o \left[1 + \frac{a^2}{2(1-a^2)(a+b)} (1 - e^{-2(a+b)\,L_{m2}\cdot Z_2})\right] \qquad (8)$$

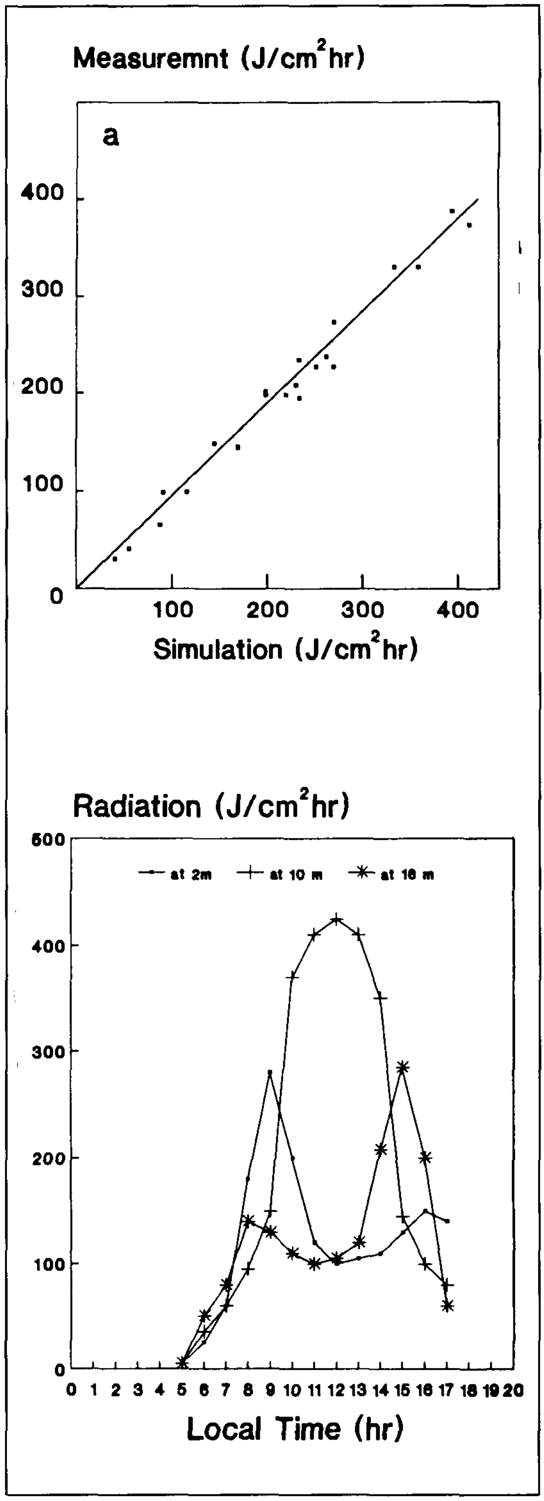

Fig. 4 Comparison of hourly accumulated simulations to measurements. a) linear relation with L_{ml}=0,3 and L_{m2}=0.1, the correlation coefficient R=0.99 for 24 April 1989; b) time dynamic relation with L_{ml}=0.6 and L_{m2}=0.2 m^2/m^3, for 18 May 1989

Table 3. Model parameters

Appearance of belt	Year	Total tree height (m)	Canopy base above ground (m)	Canopy width (m)		Leaf-area density (m^2/m^3)	
				E - W	N - S	Outer layer	Inner Layer
Disconnected	1984	4.6	2.8	2.4	2.21	1.5	1.5
	1985	5.7	2.9	4.2	4.0	0.9	0.9
	1986	7.3	2.9	5.0	5.0	0.4	0.4
Tree fence	1987	7.5	3.4	6.0		0.7	0.23
	1988	9.0	4.2	8.0		0.7	0.23
	1989	11.0	5.0	10.0		0.6	0.20

$$[\frac{1-a^2+a^2 \cdot L_{m1} \cdot Z_1}{1-a^2} \cdot e^{-(a+b)\, L_{m1} \cdot Z_1}]$$

As for the scattered radiation, it can be assumed to be isotropic and the rays from all directions are viewed as having the same intensity I', so that

$$I' = SD/\pi \qquad (9)$$

where SD is the intensity of scattered radiation, which takes on the form

$$SD = \int_0^{\frac{\pi}{2}} dh \cdot \int_0^{2\pi} I' \cdot G(h,A) \cdot \cos h \cdot \sin h \cdot dA \qquad (10)$$

with A = the ray's azimuth, h = ray's elevation angle, G(h, A) = transmittance of rays through the tree belt at A and h, the process of which can be approximately expressed by the equation of direct solar radiation.

Radiation distribution caused by ground reflection -

The light reaching the ground is reflected onto the canopy by the underlying surface with wheat leaves. Because of the small amount of reflected radiation and the semi-ellipsoid canopy, small at top and large at base, only the radiation received by the bottom of the canopy is considered (as shown in Fig. 3). For h, the initial value of radiation arriving at m_1 and going through reflection twofold is $GI(m_1)$, thus

$$\Delta GI(m_1) = GI(m_2) \cdot R_1 \cdot R_2 \qquad (11)$$

where R_1, R_2 are the reflection rate of wheat and *Paulownia* leaves respectively, and $GI(m_2)$ is the intensity of scattered radiation at m_2. The reaction between m_1 and m_2 for the radiation is

$$m_2 = m_1 + 2HL \cdot ctgh - 2n \cdot L \qquad (12)$$

in which L = the spacing between the tree rows and n = the number of tree rows between m_1 and m_2.

Definition of Parameters of the Model - Reflection, transmittance and absorption -

Without consideration of the seasonal change in leaves, the sun's elevation angle is the main factor affecting leaf's reflection. Reflection rate (albedo) ranges between 17.4-25.2%, which changes versus the elevation angle h, as shown in Table 1. It can be seen that the albedo decreases vs. the increased

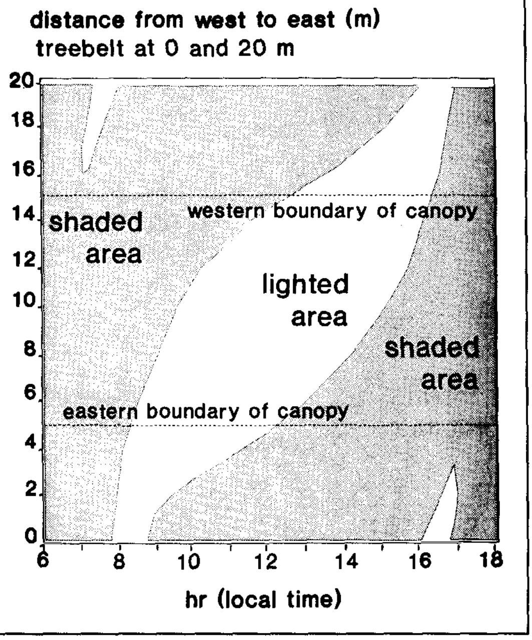

Fig. 5 Space-time variation of shaded area in a PCI field (spacing of 5 x 20m). The shaded area denotes shadow of the tree belt and the clear region of sunshine

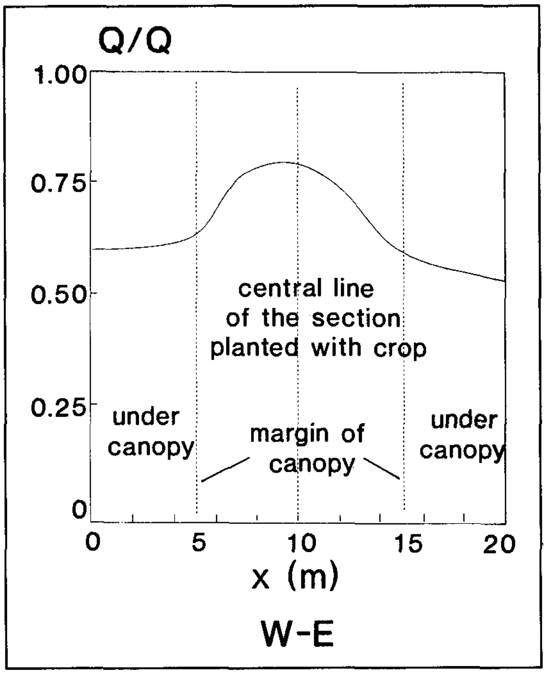

Fig. 6 Horizontal distribution of relative radiation in a PCI field with a 20m spacing between tree belts under a normal overcast sky

angle, with minimum reflection at noon. Accordingly, *Paulownia* leaf's reflection (PR) has the form

$$PR = -0.002373h + 0.34494 \quad (R^{**} = 0.95) \qquad \textbf{(13)}$$

and the expression for *Paulownia* transmittance takes the form

$$PT = 0.00230545h+0.3053311 \quad (R^{**}=0.98) \qquad \textbf{(14)}$$

Following the astronomical formulae, the sun's elevation angle is

$$\sin\delta = \sin\varepsilon \bullet \sin L \qquad \textbf{(15)}$$

$$\sin h = \sin\phi \bullet \sin\delta + \cos\delta \bullet \sin t \qquad \textbf{(16)}$$

$$\cos h \bullet \sin A = \cos\delta \bullet \sin t \qquad \textbf{(17)}$$

$$\cos h \bullet \cos A = -\sin\delta \bullet \cos\phi + \cos\delta \bullet \sin\phi \bullet \cos t \qquad \textbf{(18)}$$

where ε = the angle between the elliptic and equator (=23.45°), ϕ = latitude, L = celestial longitude and t = hour angle. L and t can be found, respectively, using the following expressions

$$L = \frac{2\pi(J_d-1)}{365} \qquad \textbf{(19)}$$

$$t_s = t_{ct} + \Delta t_{log} + t_{eq} \qquad \textbf{(20)}$$

where J_d is the nth day of the year, t_{ct} is the hour of Beijing Standard Time, Δt_{log} is the time difference at different latitudes and t_{eq} is the time difference which has the form

Substitution of (15), (19) - (21) into (16) - (18) yields the sun's elevation and azimuth angle at any time. Since a two-dimensional condition is considered, the light projected onto the leaf does not represent a real elevation angle. The relationship between the angle m of the light on the leaf with the horizontal surface and the sun's elevation angle h should be

$$t_{eq} = \frac{12}{\pi}(0.000075 + 0.001868\cos L - 0.032077\sin L - 0.014615\ 0000849\sin 2L) \qquad \textbf{(21)}$$

$$t_g \bullet m = \frac{t_g \bullet h}{\sin A} \qquad \textbf{(22)}$$

Length of light penetration in the canopy -

The slope of light incident onto a point (x_o) is found from (22). The intersection of the trunk with the ground is taken as the origin of the coordinate system with the eastward surface as axis x (for the

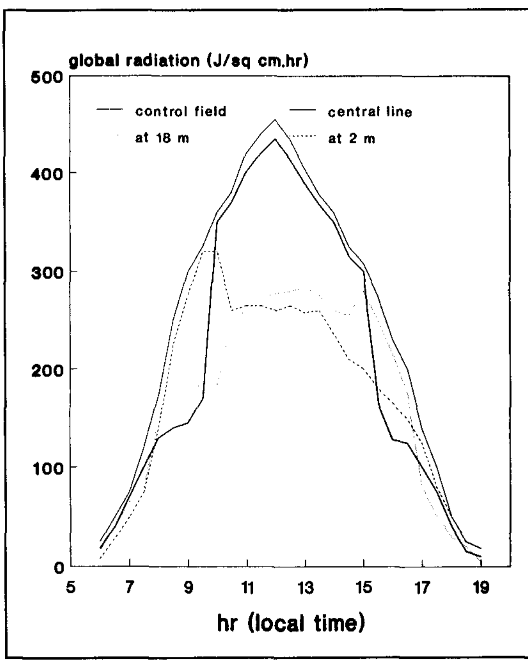

Fig. 7 Time variation of circle radiation at different distances from the tree belt in a PCI field on a fine day (24 April 1989)

distance from the tree) and the vertical as axis z (for the depth of light penetration through the canopy), and the relationship between z and x is of the form

$$Z = t_g \bullet m\ (x - x_o) \qquad (23)$$

And the elliptic equation for the canopy in this system is of the form

$$\frac{4(x-M \bullet L)^2}{D^2} + \frac{(Z-B)^2}{C^2} = 1 \qquad (24)$$

where the notation is the same as in Fig. 1. Values of Z for light penetration can be found from (23) - (24).

Parameters for the model -

Tree height = 11, canopy width = 10, distance from the ground to the base of canopy = 5 and height of wheat stand = 1 m.

Results and Discussion

Verification of Simulated Values -

The movement of leaves due to wind causes instability of their changing positions which make it hard to understand regularities of radiation measurements, and to make comparison with the simulations. If, however, the accumulated values from simulation are changed into accumulated values of radiation in an hour for each point in the field of PCI, high correlation is found between the simulations and measurements, and the linear relation is shown in Fig. 4a, Fig. 4b illustrates the time dynamic diagram of simulations and measurements for different distances from the tree belt, showing high agreement. Thus, we are led to believe that the computer-run model presented fits entirely with quantitative description of the radiation distribution in the field of PCI.

Space-Time Distribution of Tree Shadow -

The underlying surface of the field receives solar radiation in varying amounts because of the shading. Fig. 5 shows the computer-simulated variation in shaded and nonshaded areas in one day with the 20 m row spacing of the tree belts. It depicts that between 5:35 and 7:00 am the field surface is under shadow of varying degrees because of small elevation angle of the sun and overlapping shading of multiple belts. After about 7 am a small patch of shine begins to appear on the sunny side of the opposite belt owing to low elevation angle. It moves to the middle between the belts as the sun rises, followed by the increasing light-shine area and decreasing shaded area with the maximum light during noon and shaded area formed by the vertical shadow. After 12:00 reversal happens in the variation in the shaded and non-shaded areas. It follows that insolation for a point in the field is much less in hours than in an open field. Fig. 5 shows that the surface near the tree belt is shaded for most of the day, and the more distant the ground from the belt, the more insolation it gets, and thus the middle part between belts obtains maximum insolation. Table 2 summarises daily insolation hours at various distances from the belts.

Space-Time Distribution in Radiation in a PCI Field -

The normal overcast day is defined as no direct solar radiation available and the radiation is of scattered type received by the area from all directions of the sky. Evidently, scattered radiation of a point is related to the transmittance of the tree belt and the shaded portion of the sky. The nearer to the belt, the greater the portion is it, resulting in a symmetric curve for the relation between the radiation and distance from the belt (see Fig. 6). The scattered radiation of the surface outside the belt changes with time. Relative radiation under the canopy is independent of time in the horizontal pattern. This is because the shading effect of the canopy on the surface below does not change with time and also because the total transmittance is time-independent in view of scattered radiation coming from all directions of the sky.

Distribution on a clear day -

The radiation distribution in the PCI field from a clear sky is quite different from an overcast sky,

Table 4. Q_m/Q_o in various PCI fields.

Year	Spacing between tree belts (m)					
	10	20	30	40	50	60
1984	0.93	0.96	0.98	0.98	0.98	0.98
1985	0.83	0.91	0.94	0.96	0.97	0.97
1986	0.72	0.86	0.91	0.93	0.94	0.94
1987	0.68	0.84	0.90	0.92	0.93	0.93
1988	0.59	0.79	0.86	0.90	0.92	0.93
1989	0.32	0.65	0.78	0.84	0.87	0.89

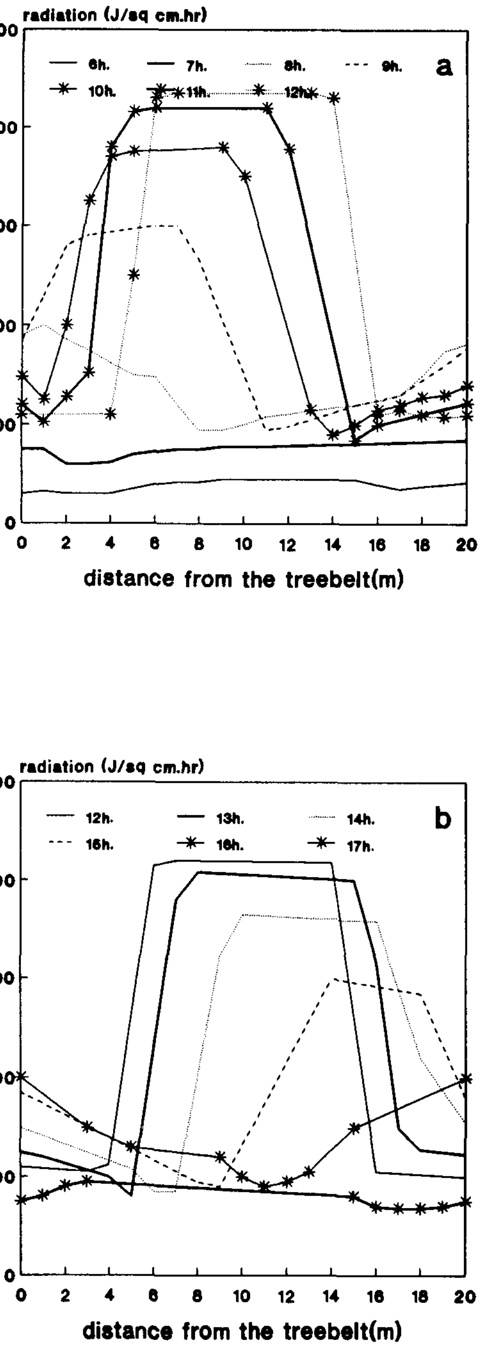

Fig. 8 Hourly variation in the daily radiation condition at different distances from the tree belt (m) in a PCI field with a 20m spacing between tree belts on a clear day (15 May 1989). a) morning hours; b) afternoon hours

because on a fine day both scattered and direct radiation is available, with the former much less than the latter. Now we denote atmospheric scattered radiation by q, the solar radiation with (without) particulate scattering by Q_o (Q_m), and the radiation distribution inside the field is related to time (which is represented by the sun's elevation angle h for a given point). Following Albert (1951), the relationship can be written as:

$$q = K (Q_o - Q_m) \bullet \sin h$$

where K is the constant with the evaluation of 0.5.

Fig. 7 shows the daily course of circle radiation at different distances from the tree belt. It can be seen that for the 20 m row spacing, the tendency of time variation in radiation around the central line, 10 m from the belt on both sides each has the following features. The tendency of radiation change along the central line of the field for two hours before and after noon, evening and early morning is similar to, but slightly lower in value than, the open field. However, a marked low value interval around 9 am and 4 pm in the PCI field corresponds to the high-value interval on the curve of circle radiation at 2 m eastward away from the belt and 2 m westward from the eastward belt. This is due to the fact that light intensity is greater at the distant point than at the one nearby on the field at the initial and terminal period of sunshine striking the surface across the tree top belt. With the radiation strongest during four hours around noon any point 2 m away from the tree belt is heavily-shaded, causing decreased radiation in contrast to the situation at the central line.

Radiation intensity of a point varies greatly from place to place, depending on the sun's elevation angle, which leads to corresponding changes in the horizontal distribution in the daily course. Fig. 8a and b show the hourly variation of solar radiation in the morning and afternoon hours, which can be divided into intense and weak radiation intervals with a marked transition. The intense interval corresponds spatially with the light-shine area, with small variation in the horizontal distribution, slightly lower in amount than in the open field. And the weak interval, although in agreement with the shaded area, has greater variation, which is related to the path through the canopy and shaded portion of the sky. The longer the path bigger is the value of Z, smaller the radiation on ground. The shaded area has much smaller absolute radiation intensity than the light area and the intensity gets

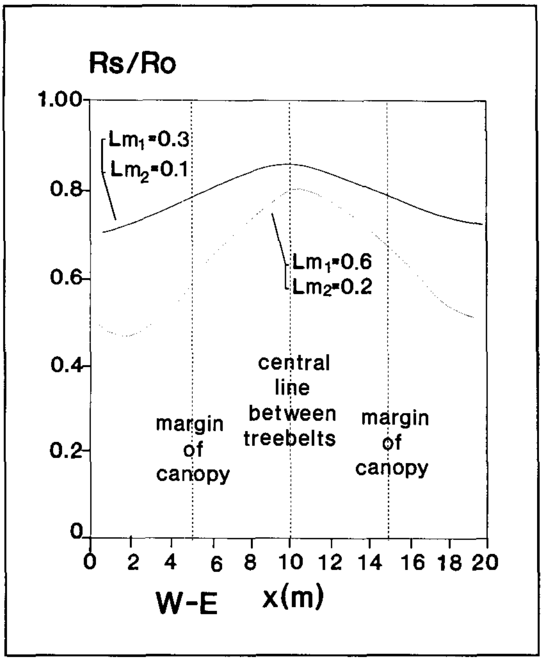

Fig. 9 Horizontal distribution of daily total relative radiation in a PCI field with a 20m tree belt spacing

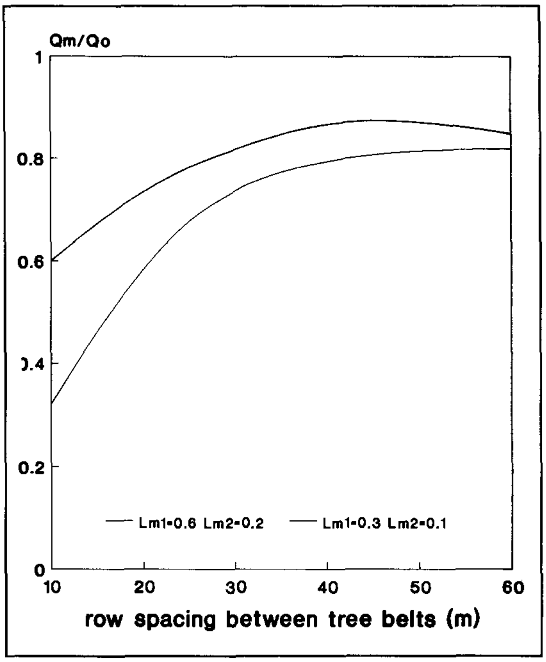

Fig. 10 Relationship between the row spacing of the tree belts and Q_m/Q_o

decreased with increased radiation in an open field. As shown in Fig. 8, the bigger the intensity over the light area, the smaller is the shaded area on the same curve. This is because the light intensity corresponds to the higher elevation angle, causing low transmittance of rays through the leaves. Again in Fig. 8 one can see the correspondence between the various intervals of the field and the time of the highest value of radiation. Starting from the westem tree belt, the time for maximum radiation at different distances from the tree are as follows: - 9 hrs at 1-2 m; - 10 hrs at 3-4 m; - 11 hrs at 5 m; 12 hrs at 6-14 m; - 13 hrs at 15 m; - 14 hrs at 16-17 m and - 15 hrs at 18-19 m.

Although remarkable difference occurs in the daily course of radiation for points equally away from the tree belt on both sides, little discrepancy is found in the daily total for related points. Fig. 9 shows variation in the horizontal distribution of daily total radiation in a PCI field - variation showing normal distribution, with maximum total at noon and smaller away from the tree belt, depending on the leaf-area density for the decrease in magnitude. However, if the ratio of the daily radiation at a point in the field (R_s) to that in an open field (R_o) is defined as the relative daily total (R_s/R_o), then the ratio for points at different distances from the belt may differ greatly, depending on the leaf-area density (L_m). As a rule, it has L_m 0.3 in the blooming and leaf-growing period of *Paulownia*. For L_m = 0.3, the ratio 0.85 at the central line between tree belts in a PCI field it has the value of 0.75 below the canopy, with small peak - valley undulation on the curve. During the in-leaf period, L_m reaches 0.6 m/m^3, although R_s/R_o remains close to 0.85 at the central line but it becomes 0.50 below canopy and near the tree belt because of sharp decrease in total radiation, with marked peak-valley undulation on the curve. Therefore, when winter wheat and *Paulownia* are intercropped in a field, wheat stands are not much shaded until the blooming and leaf-growing of the trees and the stands much the same regardless of the location. In addition, the wind force decreases, warming effect and soil water maintenance due to the tree belt which creates microclimatic effect to make the wheat grow better in the PCI field than in open field. However as the leaf-area density increases the shading effect dominates among the factors involved, leading to decreased total amount of radiation and difference in the horizontal distribution which are responsible for the slowing-down of wheat growth and difference between stands below and farther away from the trees. Obviously, the wheat growth nearer the belt is reduced. In summer the leaf-area density of *Paulownia* in-

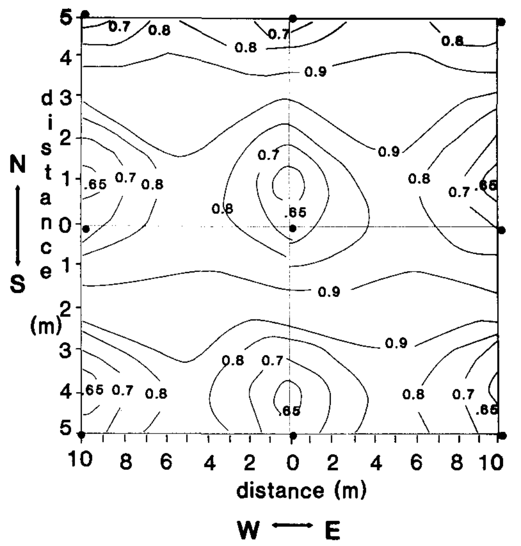

Fig. 11 Spatial distribution of computer-simulated Qm/Qo in an early PCI field with 10m spacing of tree belts. The curves are isopleths

creases, the summer crops are heavily shaded from the very beginning, thus leading to increasing difference among cotton, corn and sweet potato below and farther away from the tree belts, resulting in an increase in the low-yield area close to the tree belts and diminishing of the high-yield area in the middle of the field. Hence, the yield increase in this case depends on the stand, row spacing and leaf-area density of *Paulownia.*

Optimal Structure of Tree Arrangement in a PCI Field Based on Radiation Distribution -

We investigated the radiation with tree belt spacing of 20 m. It can be inferred that with the belts oriented S-N the horizontal distribution of radiation in these fields should be similar for a variety of row spacings of the belts except for the difference in the starting of sunshine, insolation hours, dynamic proportion of the light-shine area to that of the shaded area and variation in radiation for a given point. As shown in Table 2, the difference in sunshine duration for various patterns of PCI and distances from the tree belt indicates that the insolation length increases with the row spacing of the belts for a given point, but the growth rate of insolation duration decreases with the increase in the row spacing, resulting in zero growth near the belt for the row spacing 40 m. Simply from the viewpoint of radiation one may think that the optimal spacing between the tree belts should be as far as possible, thus minimising the effect of radiation on the crop on both sides of the field. However, computer simulated results show that for 40 m row spacing, the insolation length increases very little for any point in the PCI field, and the 40 m spacing is able to provide more average benefit economically, for a unit area, than with other spacings. It is found that the 40 m spacing between the belts is optimal for 6-year old trees.

The ratio of average daily total radiation 9 (Q_m) obtained from points in fields of various PCI to the daily total of an open field (Q_o) is used as the indicator of daily total received by the crop of the field. Fig. 10 summarizes the ratio Q_m/Q_o, showing that for 40 m spacing the daily total gets a bit higher. The curve trend indicates little effect of increased leaf-area intensity and 40 m spacing is optimal for the intercropping.

Extension of the Model -

Above analyses were done on the basis of 6-year old *Paulownia* belts with canopies grown into a fence. To examine the radiation distribution before connection of canopies, the model is modified as follows:

i) with $L_{m1} = L_{m2}$ for the canopy and leaf stratification still at early stage;
ii) Transformation of 2-dimensional into 3-dimensional coordinate system for the expression of the distance sun's rays travel inside the canopy.

The early-stage *Paulownia* has its branches and thus canopy disconnected with those on both sides, and so the tree belts bring about particular radiation pattern not merely in the field between themselves but between stands.

Fig. 11 shows the simulations of Q_m/Q_o for tree belts at 10 m row spacing (with the parameters in Table 3 fed into the model). It can be seen that the low-value center is located about 1 m on the north side of the tree with the contour delineating an ellipse, major axis in the E-W direction. Hence, only local wheat stands arranged in the same direction were heavily damaged by the shading effect of the trees.

Based on the parameters of paulownia growth in a PCI field (see Table 4) the interannual dynamic variations of Q_m/Q_o are listed in Table 4 for various structures of PCI, indicating again that the optimal tree belt spacing remains 40 m for the 6-year old trees, with little difference in radiation in the spacing 40 m and the 40 m spacing unadopted. Further, from the simulations it can be inferred that for the first three years (1983-1985) the optimal is 10 m row spacing; for 1986-1987, 20 m and for 1988, 30 m. However, these results were obtained based on the radiation measurements, which are subject to modification, depending on other factors.

Conclusions

1) Analysis was done of the change in shaded area, sunshine hours and of spatial and temporal variations in radiation at various distances from the tree belts.
2) On this basis, the optimal belt spacing in a PCI field is 40 m for 7-year old *Paulownia*, but for earlier tree stages the optimal spacing should be increased progressively.
3) Following the principles and scheme presented, only a limited number of data on the geometry of the configuration and biological features of *Paulownia* and radiation in an open field are needed to be fed into a computer to get the radiation pattern at any point of any field of PCI with various structures. The deficiency of the scheme lies in the lack of data relating various amounts of cloudiness (except a normal overcast and clear sky) to surface radiation. So further work is necessary.

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Economic Evaluation Of Intercropping With *Paulownia* - Optimisation And Choice Of Intercropping Models

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ABSTRACT

The purpose of this paper is to demonstrate the optimum Paulownia-crop intercropping (PCI) model, and to guide farmers in the scientific management and further expansion of PCI technology. After wide investigation of various PCI models with many crops and various planting spacings, the author reports on three models which have different rotations and intercropping densities. The data gathered were analysed with computer according to economic principles and evaluation methods. The benefits and practical application of the models were tested. On the basis of monetary value, the model that showed the highest net income was chosen. Next a model was chosen that made optimum use of available land resources with multiple objectives. The four main objectives were: 1) increased income; 2) guaranteed food production; 3) long-term profit level; and 4) long-term growth rate per unit of land. Sensitivity analysis was also made to study the effects of indeterminate factors which may effect the model. Finally, data from crops in the optimum model were compared with crops on non-intercropped land and benefits for farm application are discussed.

Introduction

China is a large agricultural country lacking in land resources. There is an average cultivated area of 0.1 ha per capita at present and this is decreasing yearly. Therefore, land use has become the most important problem for agricultural development. In order to make full use of land resources, farmers have been practising *Paulownia*-crop intercropping for a long time, so as to meet the demand for not only food, but also timber, fodder, fuel and money.

Various *Paulownia*-crop intercropping (PCI) models which were suitable for the local natural and economic conditions had been developed by Chinese farmers over a long period of time. At present, there are 3,000,000 ha of PCI area in China. The PCI models have played an important role in preventing natural disasters, improving the ecological environment, adjusting rural industry structures, increasing land productivity, farmers' income and the rural economy. But, the development of these PCI models lacked scientific direction and application of advanced techniques over long term. Some of them are not economically and ecologically sound so that PCI could not be further expanded in larger regions. In order to solve this problem, an analysis and evaluation of the economic benefits of PCI was made to select the optimum model. This will guide farmers to manage the PCI scientifically and play a role in the expansion of PCI.

Current State of PCI in China and Classification of PCI Models

At present, most of PCI fields are distributed in northern China in Hebei, Henan, Anhui and Shandong provinces, with about 2,866,000 ha developed in 1970s. Some of them were cut over two or three

Table 1. Net present value (discount rate = 8%) (US$/ha).

Model	Rotation	Control	5 x 6	5 x 10	5 x 20	5 x 30	5 x 40	5 x 50
	1	777.28	787.20	796.57	806.35	792.96	808.45	805.69
	2	1496.98	1710.39	1652.78	1605.03	1585.75	1593.79	1583.99
	3	2163.37	2658.01	2469.95	2375.45	2342.44	2349.05	2341.38
	4	2780.39	4268.33	3812.11	3381.58	3258.60	3184.74	3158.86
	5	3351.72	5222.10	4647.96	4144.65	3963.78	3884.75	3855.34
1	6	3880.72	6718.08	5780.38	5017.39	4750.00	4639.43	4596.85
	7	4370.53	7769.45	6618.07	5720.42	5433.51	5293.24	5241.59
	8	4824.07	9516.17	7850.43	6594.72	6216.03	6015.95	5927.44
	9	5244.00	10601.51	8634.66	7205.09	6791.99	6582.31	6479.78
	10	5632.84	12070.29	9600.41	7877.58	7398.26	7173.76	7043.69
	11	5992.87	13182.24	10309.27	8417.08	7901.05	7684.21	7540.87
	12	6326.23	13162.66	10291.48	8572.41	8136.72	7951.40	7865.58
	1	695.80	718.79	723.41	724.99	707.88	722.51	725.56
	2	1340.60	1605.41	1527.76	1461.42	1427.94	1436.06	1429.05
	3	1936.60	2389.61	2290.14	2174.17	2133.42	2114.37	2102.37
	4	2488.94	4082.11	3601.64	3156.88	3016.91	2910.63	2863.08
	5	3000.38	5026.61	4402.59	3896.39	3705.24	3588.95	3522.73
2	6	3473.94	6496.19	5514.16	4718.51	4459.83	4310.63	4220.56
	7	3912.40	7531.20	6340.84	5405.20	5117.27	4935.50	4829.21
	8	4318.39	9297.91	7573.76	6259.43	5865.37	5631.74	5480.08
	9	4694.31	10410.38	8358.73	6860.33	6417.82	6168.54	5995.78
	10	5042.38	11904.28	9329.52	7529.44	7000.31	6731.20	6525.91
	11	5364.67	13039.49	10047.41	8070.53	7480.91	7216.23	6989.79
	12	5663.09	13041.45	10041.64	8229.81	7692.44	7458.33	7278.40
	1	1193.76	1199.52	1204.09	1218.70	1202.27	1216.45	1219.93
	2	2299.10	2533.95	2459.16	2414.40	2373.01	2377.66	2371.75
	3	3322.56	3684.42	3647.80	3546.48	3493.84	3481.36	3470.22
	4	4270.21	5512.13	5232.90	4893.30	4287.89	4697.17	4654.66
	5	5147.66	6593.29	6271.98	6037.90	5913.70	5818.74	5769.86
3	6	5960.11	8130.06	7579.94	7144.26	6942.36	6849.74	6800.72
	7	6712.38	9122.14	8499.18	8020.40	7803.69	7738.06	7673.30
	8	7408.93	10754.43	9727.12	9050.13	8736.14	8693.06	8573.82
	9	8053.89	11742.42	10434.53	9760.69	9441.39	9446.64	9331.91
	10	8651.06	13121.06	11255.19	10468.10	10113.50	10168.85	10068.86
	11	9204.01	14149.56	11850.12	10988.24	10632.25	10764.43	10697.61
	12	9515.99	14052.70	11745.54	11068.97	10828.66	11065.26	11101.43

times. The PCI models are mainly *Paulownia* + wheat + cotton, *Paulownia* + wheat + millet, *Paulownia* + wheat + corn + bean, *Paulownia* + wheat + peanut, and *Paulownia* + wheat + sweet potato. Among them, the planted area of the first three models is more than 90% of the whole planted area. The benefits of these three models are better than others, so they are accepted and expanded by farmers because China has more than 1.1 billion population, the supply of food and clothing are of primary importance.

In the aspect of *Paulownia* planting, the first problem is intercropping density. The existing densities are 5 x 6, 6 x 12, 5 x 20, 5 x 30, 6 x 30, 5 x 40, 5 x 50 m. The lower densities have been widely adopted to guarantee food production. Among them, the areas of 5 x 20 and 5 x 40 m are more than 70% of the all PCI area. The second problem is harvest age. *Paulownia* grows very fast so that it could be cut for use in the 4th year after intercropping. The diameter at breast height could reach 30 cm in the 8th year of inter-cropping. Most farmers adopt the short rotation. All the trees would be cut within ten years of intercropping. The rotation of each farm household is different from each other, depending on the actual financial need of the family such as family sickness, wedding, funeral, etc. Farmers cut trees to pay for the expenses. In con-

Table 2. Single objective optimum model (A).

Model	Spacing (m)	Rotation (yr)	NPV(US$/ha)
1	5 x 6	11	13182.24
2	5 x 6	12	13041.45
3	5 x 6	11	14149.56

Table 3. Single objective optimum model (B).

Model	Spacing (m)	Rotation (yr)	MNI(US$/ha)	ANI(US$/ha)
1	5 x 6	11	3729.46	2180.66
2	5 x 6	11	3729.46	2193.47
3	5 x 6	11	3726.46	2116.67

ventional management, it is necessary to choose the optimal rotation or harvest age. This point is still not clear to most farmers.

The abovementioned basic PCI models were developed during long-term productive practices, which have a certain rationality. If being scientifically guided and further improved, their roles would be greater. The purpose of this paper is to estimate the economic benefits of the existing basic model.

The research subject was divided into three groups, i.e., *Paulownia* + wheat (Model 1), *Paulownia* + wheat + bean (Model 2), and *Paulownia* + wheat + cotton (Model 3). According to the experiment, the effect of intercropping density to crop yield primary depends on the size of line-distance. Therefore the line-distance was changed. Six kinds of densities have been chosen, i.e., 5 x 6, 5 x 10, 5 x 20, 5 x 30, 5 x 40, 5 x 50 m. Intercropping years were from 1 to 12. The different rotations of different density of each model were studied and the optimum density and rotation of each model was determined.

Collection and Sorting out the Data -

Minquan and Luyi Counties in Henan Province and Dangshan County in Anhui Province were chosen for study. The data collected included crop yields from each year of each density of the three groups of models. Also, growth information of *Paulownia,* production costs, market prices of farm products, *Paulownia* products, crop yields and the cost of the control plots for each model were available which was sorted and the data adjusted. Thus, the average crop yield for each year at different densities of the three models and their corresponding control plots, growth information of *Paulownia,* average management cost and the average market prices were calculated.

Several Suppositions -

The objective of this research was to find the optimum density and rotation of PCI. The experiment was carried out with following suppositions: i) The natural conditions and level of management and input of intercropping land is the same as control land. ii) The management costs of each year are the same. iii) The growth state of *Paulownia* in each model is the same.

Data Treatment -

In order to remove the effects of the differences of the environment, level of input and management of the crop, the designed yield at each density was calculated by calculating the yield of intercropping land to that of control land. The formulae are as follows:

$$D_n = R_n \times C_a \ (R_n = I_n/C_n \times 100\%;\ C_a = \sum_{1}^{12} C_n/12)$$

$$D_n = I_n/C_n \times 100\% \times \sum_{1}^{12} C_n/12$$

Where:

D - designed yield of crop in year n of inter cropping,

R_n - relative yield of crop in year n of intercropping,

I_n - crop yield of intercropping land in year n,

C_n - crop yield of control land in year n,

C_a - average yield of control over a 12-year period.

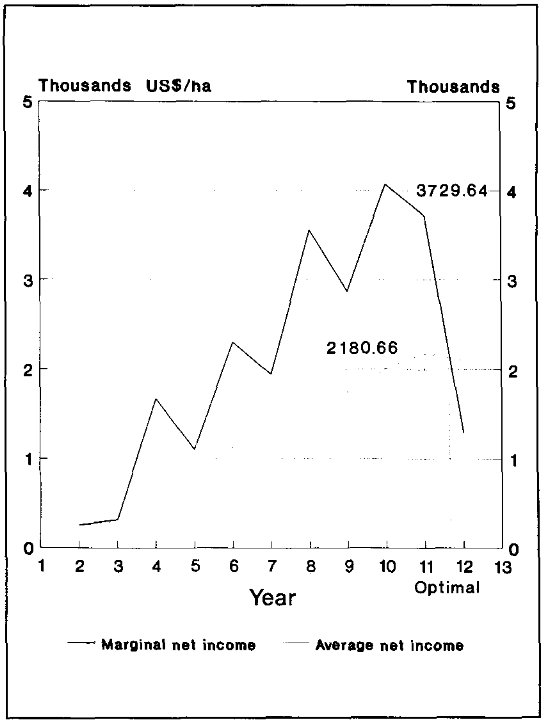

Fig. 1 Showing increase in net income Model 1

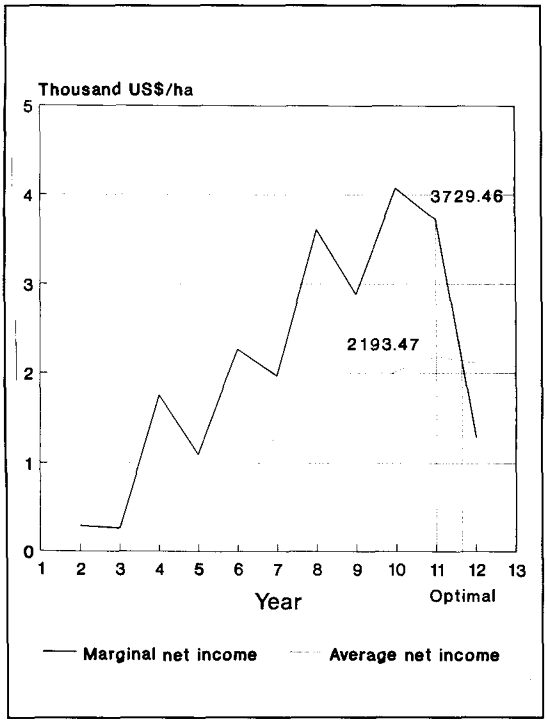

Fig. 2 Showing increase in net income Model 2

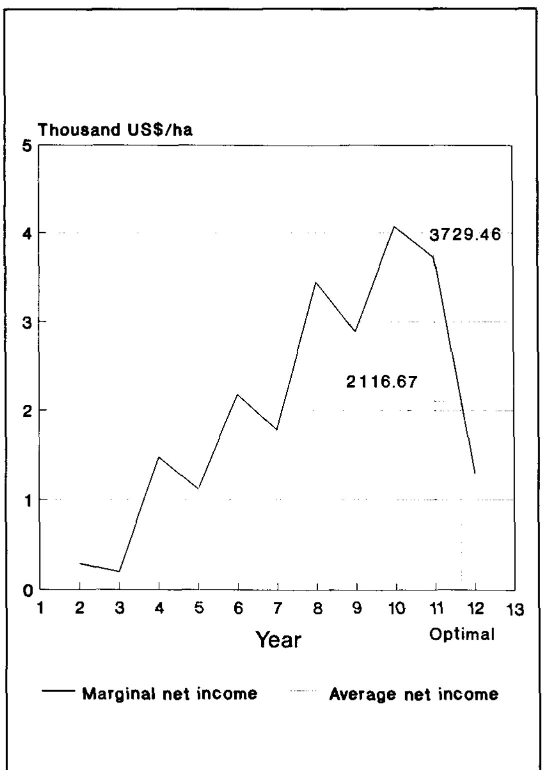

Fig. 3 Showing increase in net income Model 3

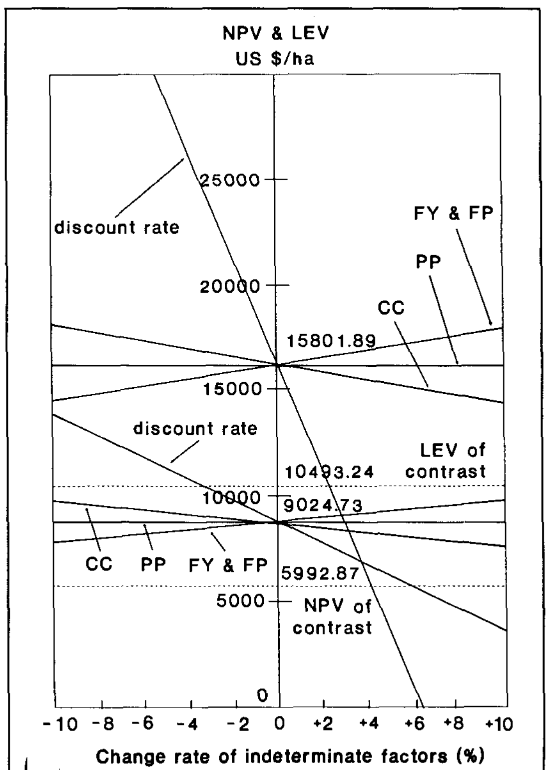

Fig. 4 Showing increase in net income Model 4

Table 4. Wheat relative yield (WRY) (%).

Year	Control	5 x 6	5 x 10	5 x 20	5 x 30	5 x 40	5 x 50
1	100	100.0	101.0	102.0	101.0	103.0	103.0
2	100	100.0	101.0	101.0	101.0	102.0	102.0
3	100	90.0	98.0	102.0	104.0	103.0	104.0
4	100	82.0	95.0	103.0	107.0	103.0	105.0
5	100	73.0	86.0	102.0	105.0	107.0	107.0
6	100	68.0	90.0	99.0	103.0	107.0	109.0
7	100	67.0	86.0	98.0	107.0	107.0	108.0
8	100	56.0	75.0	93.0	100.0	104.0	105.0
9	100	49.0	67.0	84.0	90.0	97.0	99.0
10	100	46.0	61.0	77.0	85.0	96.0	98.0
11	100	42.0	53.0	76.0	82.0	96.0	99.0
12	100	36.0	42.0	68.0	75.0	81.0	95.0

Table 5. Benefit-cost rate (BCR) (%).

Model	Rotation	5 x 6	5 x 10	5 x 20	5 x 30	5 x 40	5 x 50
	2	256.10	262.52	267.55	267.97	271.68	271.71
	3	271.68	274.30	274.92	275.03	276.83	277.03
	4	328.70	313.26	295.63	290.70	287.46	286.58
	5	336.36	318.16	300.07	293.19	290.25	289.35
	6	365.86	336.11	310.01	300.47	296.62	295.30
1	7	375.41	341.33	313.19	304.00	299.47	297.96
	8	407.63	360.41	323.13	311.73	305.60	302.98
	9	416.89	364.32	324.62	313.05	307.11	304.26
	10	437.25	374.28	328.92	316.23	310.28	306.82
	11	447.34	377.40	330.14	317.21	311.82	308.20
	12	429.45	362.77	322.23	312.02	307.72	305.79
	2	260.70	266.02	269.69	269.70	272.68	273.06
	3	276.21	279.30	278.46	278.00	277.87	277.74
	4	342.02	323.99	303.82	297.30	291.58	289.18
	5	352.24	330.02	310.05	301.89	296.61	293.60
	6	385.17	350.93	320.65	310.50	304.40	300.69
2	7	396.65	357.76	325.13	314.91	308.13	304.15
	8	434.25	380.20	336.75	323.51	315.42	310.19
	9	446.23	385.48	339.12	325.25	317.25	311.60
	10	470.26	397.47	344.68	328.95	320.86	314.54
	11	482.61	401.79	346.79	330.15	322.68	316.08
	12	463.61	386.26	338.63	324.33	318.13	313.23
	2	275.64	280.30	285.02	284.64	286.43	286.83
	3	284.47	290.13	290.72	289.91	290.25	290.24
	4	319.53	315.16	306.20	303.24	300.44	299.12
	5	320.78	315.72	311.97	309.06	306.42	305.11
	6	337.27	326.42	317.23	312.37	311.17	309.04
3	7	337.92	326.32	316.98	312.25	311.03	309.60
	8	355.35	335.36	322.15	315.49	314.95	312.31
	9	357.45	332.79	320.66	314.40	315.00	312.67
	10	368.61	334.19	320.52	313.94	315.56	313.71
	11	372.93	332.10	317.74	311.51	314.56	313.48
	12	357.29	318.20	307.91	304.15	309.00	309.91

Table 6. Land expected value (LEV) (US$/ha).

Model	Rotation	5 x 6	5 x 10	5 x 20	5 x 30	5 x 40	5 x 50
	2	11989.17	11585.35	11250.64	11046.10	11171.85	11103.16
	3	12455.92	11980.29	11521.92	11361.81	11393.87	11356.67
	4	16108.72	14386.94	12762.11	12297.99	12019.24	11921.57
	5	16348.85	14551.39	12975.68	12409.43	12162.01	12069.93
	6	18165.30	15629.81	13566.73	12843.72	12544.75	12429.61
1	7	18653.71	15889.35	13734.18	13045.34	12708.56	12584.56
	8	20699.42	17076.13	14344.73	13521.01	13085.81	12893.27
	9	21213.58	17277.92	14417.35	13590.72	13171.18	12966.01
	10	22485.36	17884.30	14674.89	13781.98	13363.77	13121.47
	11	23081.49	18051.06	14737.92	13834.37	13454.70	13203.72
	12	21832.74	17070.35	14218.95	13496.27	13188.89	13046.54
	2	11253.30	10709.01	10243.99	10009.31	10066.22	10017.09
	3	11590.61	11108.14	10545.63	10347.98	10255.58	10197.37
	4	15405.92	13592.62	11914.09	11385.85	10984.72	10805.29
	5	15736.83	13783.21	12198.45	11600.01	11235.94	11028.63
	6	17551.80	14909.97	12758.57	12059.12	11655.69	11412.15
	7	18081.69	15223.75	12977.37	12286.08	11849.66	11594.47
2	8	20224.66	16474.32	13615.41	12758.26	12250.07	11920.18
	9	20831.13	16725.78	13727.49	12842.03	12343.22	11997.53
	10	22176.10	14379.66	14026.35	13040.65	12539.34	12156.91
	11	22831.55	17592.55	14131.13	13098.73	12635.29	12238.80
	12	21631.69	16655.94	13650.68	12759.35	12371.04	12072.59
	2	17762.01	17237.76	16924.01	16633.88	16666.48	16625.05
	3	17870.98	17693.35	17201.91	16946.58	16886.05	16832.02
	4	20802.83	19749.01	18467.36	18050.67	17727.16	17566.73
	5	20641.64	19635.72	18902.88	18514.05	18216.76	18063.73
	6	21983.21	20495.72	19317.66	18771.74	18521.30	18388.75
3	7	21901.39	20405.72	19256.21	18735.91	18578.34	18422.86
	8	23392.86	21158.27	19685.70	19002.71	18909.00	18649.64
	9	23496.53	20879.46	19531.10	18892.18	18902.69	18673.11
	10	24442.80	20966.93	19500.69	18840.12	18943.23	18756.96
	11	24775.23	20749.01	19239.90	18616.58	18848.02	18731.02
	12	23309.04	19482.18	18359.96	17961.36	18353.81	18413.80

Cash-flow Analysis of PCI Model -

From the results examined, the cash-flow analysis of different rotations at each density each model was made as follows: The cash-outflow included the establishment cost of intercropping land, i.e., the cost of purchasing and planting *Paulownia* seedlings and comprehensive cost of management term (intercropping term), i.e., expenses of crop seeds, fertiliser, water, farm-chemical, wages and others per year during management term. Its present value was calculated by the following formula:

$$C_{ot} = \frac{C_e}{(1+i)} + C_c \times \frac{(1+i)^t-1}{i(1+i)^t}$$

where

C_{ot} - present value of cash-outflow in t years of intercropping term (rotation),

C_e - establishment cost,

C_c - comprehensive cost of intercropping term,

i - discount rate,

t - years of intercropping term (rotation).

Cash-inflow -

Cash-inflow included the output value of crops and *Paulownia* products (inv. timber, branch, stock and leaves) in intercropping area. Its present value can be calculated by the following formula:

$$C_{it} = (V_t + W_t) \times \frac{N}{(1+i)^t} + \sum_{t=1}^{t} \frac{L_t x N + C_{1t} + C_{2t}}{(1+i)^t}$$

Table 7. Comprehensive scores of each model (point).

Model	Rotation	5 x 6	5 x 10	5 x 20	5 x 30	5 x 40	5 x 50
	2	23.29	22.57	21.57	20.00	21.43	21.00
	3	18.14	26.29	25.57	24.57	25.29	24.29
	4	33.43	38.71	31.86	30.00	28.71	27.71
	5	27.29	33.43	35.14	32.43	31.43	30.71
	6	34.43	47.71	41.00	37.00	35.00	34.00
1	7	38.29	41.71	44.29	40.00	38.14	37.43
	8	43.00	37.29	48.71	45.00	42.29	40.71
	9	45.00	41.14	42.29	38.86	44.29	42.43
	10	46.00	42.43	36.43	41.29	47.86	46.14
	11	47.14	43.71	38.43	44.57	50.00	48.71
	12	46.14	42.00	37.29	34.43	42.00	49.14
	2	23.71	22.57	21.71	20.00	21.29	20.86
	3	18.14	27.14	25.86	24.14	24.43	23.57
	4	33.43	38.86	31.86	30.00	28.43	27.71
	5	28.14	33.29	35.43	33.00	30.86	30.00
	6	34.43	48.14	40.86	37.43	35.29	33.71
2	7	39.86	41.71	44.29	41.00	37.71	36.57
	8	43.00	38.86	48.57	45.00	42.71	40.00
	9	45.00	41.14	42.29	38.71	44.57	42.14
	10	46.00	42.57	36.43	41.71	47.86	45.43
	11	46.71	43.86	38.43	43.86	49.86	47.43
	12	46.57	42.43	37.71	34.86	40.57	47.71
	2	23.43	22.57	22.14	20.57	21.43	20.43
	3	17.00	26.43	26.00	24.86	24.57	23.86
	4	32.14	39.29	31.71	29.71	28.57	27.71
	5	25.43	32.57	38.00	34.71	32.71	31.86
	6	31.86	46.71	43.86	39.86	37.43	35.71
3	7	34.43	39.57	45.71	41.43	39.86	38.43
	8	40.57	35.71	50.29	47.14	46.00	42.86
	9	44.43	37.29	42.86	38.00	48.43	45.43
	10	46.00	42.29	35.29	39.71	51.43	48.29
	11	47.14	42.86	36.86	39.29	52.57	50.43
	12	45.71	40.00	30.57	28.00	39.57	50.86

where

C_{it} - present value of cash-inflow in t years of intercropping term,

V_t - timber value of paulownia in year t,

W_t - value of branch and stock of *Paulownia* in year t,

L_t - leaf value of *Paulownia* in t years of intercropping term,

N - intercropping density,

C_{it} - the output value of crop 1 in year t,

C_{2t} - the output value of crop 2 in year t,

i - discount rate,

t - intercropping term (rotation).

Economic Evaluation Procedures - Choice of objective -

The purpose of PCI is to make full use of land resources, increase the output rate of land at its maximal limit and obtain the maximal economic benefits per unit area. Thus, Net Present Value (NPV) was determined as the evaluation criterion. According to previous cash-flow analysis, it can be calculated by using the following formula:

$$NPV_t = C_{it} - C_{ot}$$

The NPV of different intercropping term of each model was calculated with a discount rate of 8% (Table 1). According to Table 1, the optimum intercropping density and rotation were determined to meet the economic objective of increasing income (see Table 2). Using marginal analysis, we can determine the optimum density and rotation, too.

Table 8. Multiple objective optimum model.

Model	Marks	Spacing (m)	Rotation (yr)	NPV (US$/ha)	BCR (%)	LEV (US$/ha)	WRY (%)
1	50	5 x 40	11	7684.21	311.82	13454.70	> 90
2	49.86	5 x 40	11	7216.23	322.68	12635.29	> 90
3	52.57	5 x 40	11	10764.43	314.56	18848.02	> 90

Table 9. Optimum model (A).

Model		1	2	3
Harvest time (yr)	first	6	6	6
	second	8	8	8
	third	11	11	11
Spacing (m)	primary	5 x 10	5 x 10	5 x 10
	middle	5 x 20	5 x 20	5 x 20
	final	5 x 40	5 x 40	5 x 40
NPV (US$/ha)		9024.73	8638.34	11555.94
BCR (%)		342.84	359.47	326.34
LEV (US$/ha)		15801.89	15125.33	20233.92
WRY (%)		> 90	> 90	> 90

Undiscount net income (UNI) of each year of intercropping term can be calculated by the following formula:

$$UNI_t = [(V_t + W_t + L_t) \times N + C_{1t} + C_{2t}] - [C_e + C_c]$$

whereUNI_t - net income in year t.

Marginal net income (MNI) is as follows:

$$MNI_t = UNI_t - UNI_{t-1}$$

Average income (ANI) can be determined with following formula:

$$ANIt = \sum_{t=1}^{t} \frac{MNI_t}{t}$$

The calculated results using the above criteria were shown as in Figs. 1-3. According to marginal principles that the optimum point is at the crossing point of two curves, we can determine the optimum model (see Table 3). From the result of the single objective evaluation, we can see that the output value of *Paulownia* products is much greater than that of the crops. *Paulownia* also grows rapidly so that it makes up for a loss of crop yield as a result of too high density. Therefore, the higher the density of *Paulownia* planted, the greater was the economic benefits. The reason is that the prices of *Paulownia* products are much higher than that of farm products. Since the models A and B could not guarantee food production, they would not be used in China and they are not optimum models.

Multiple Objective Evaluation -

The purpose of developing PCI is, on the one hand, to increase farmers' income, and on the other hand, to guarantee food production. Hence, the following four objectives were chosen for comprehensive evaluation:

Objective 1

Net Present Value (NPV) - To increase income was chosen as an important objective. Because of time factors involved, farmers need to be told what density to plant and when to harvest. For maximum economic benefits to be obtained this information should be made very clear.

Objective 2

Benefit-Cost Rate (BCR) - If we want to know whether the investment is profitable, to what extent it is profitable, what time to harvest, and at what density could make a certain investment obtain maximum profits, we should use the BCR which can explain under what conditions the profit will be

Table 10. Optimum model (B)

Model	1	2	3
Harvest time (Year)	11	11	11
Cutting cycle (yr)	6	6	6
Spacing (m)	5 x 20	5 x 20	5 x 20
NPV (US$/ha)	9520.64	9169.26	12538.38
BCR (%)	360.31	380.39	348.45
LEV (US$/ha)	16670.20	16054.95	21954.12
WRY (%)	> 90	> 90	> 90

maximum and efficiency of investment is the best.

Objective 3

Land Expected Value (LEV) - Besides considering just one intercropping to undertake a term management and intercropping repeatedly on the same piece of land we should also consider the LEV to show the benefit of long-term intercropping.

Objective 4

Wheat Relative Yield (WRY) - The investigation has shown that the people in the Northern China Plain use wheat as a staple food. Of all the foods produced, most of it is wheat. Due to this statistics, each farmer must produce in excess of 250 kg of wheat per year. Therefore, WRY was used as a decision objective in choosing a model.

The four objectives are not equally important. According to the purpose of PCI, the importance of each objective is scored in order as follows:

Objectives	NPV	BCR	LEV	WRY
Scores	3	1	1	2

Here it is shown that the most important is NPV, with a value of three points, the second is WRY with two points. Among them, WRY of more than 90% is two points, 90-80% is one point and less than 80% is zero. The third are BCR and LEV, each of them is scored as one point. The scores will be taken as weighing coefficients of each objective when following comprehensive marking, so as to evaluate and set the model of PCI.

Determination of the Optimum Model -

The criteria of the four objectives can be calculated as follows (the results of the calculation are listed in Tables 1, 4, 5, 6 respectively):

NPV (see table 1)

$$WRY_n = \frac{I_n}{C_n} \times 100\% \text{ (see table 4)}$$

$$BCR_t = \frac{c_{it}}{C_{ot}} \times 100\% \text{ (see table 5)}$$

$$LEV_t = NPV_t \times \frac{(1+i)^t}{(1+i)^t-1} \text{ (see table 6)}$$

Comprehensive marking programme - First, each objective of each model will be individually marked. Each model has six kinds of density, 11 terms of intercropping, i.e., 2-12 years. Total has 6 x 11 = 66 kinds of choices. Hence, the highest marks of each objective will be 66 points, the lowest mark will be one point. The greater the value of criterion, the higher the marks will be. Then, according to the importance of each objective, the marks of each objective will be weighted, averaged and each model will obtain a comprehensive mark. The result of comprehensive marking is shown in Table 7.

Determination of optimum density and rotation - From the above result of multiple objective evaluation, we can see that using comprehensive marking can meet the requirements of four objectives to avoid the limitation of concentrating on income alone. This model is suitable for Chinese conditions and will be easily expanded and received by farmers. Meanwhile, it confirms the practicality of the model to be practised by farmers over a long period of time. This is why the model is similar in density to that mentioned in a previous chapter. If we use marginal analysis methods, the same result would be obtained. The aforementioned optimum model is the result of computer calculations, and can be further perfected by taking other aspects under consideration (Table 8).

Practice of intermediate cutting - Table 7 shows the value of rotation of six years at a density of 5 x 10 m and rotation of eight years at a density of 5 x 20 m which are second only to the value of rotation of 11 years at a density of 5 x 40 m which is of highest value. With the primary density of 5 x 10 m, the first intermediate cutting would be in year 5 of intercropping and the density would decrease to 5 x 20 m, second intermediate cutting would be in year 8, then the density of 5 x 40 m would be maintained until the final cutting. Thus, there will be three cuttings in eleven years. The benefit was calculated as follows:

1) Net Present Value:

$$NPV = P_{6,20} + P_{8,40} + P_{11,40} + Q_{6,10} + Q_{8,20} + Q_{6,20} + Q_{11,40} + Q_{8,40}$$

where:

$P_{i,j}$ - NPV of *Paulownia* in year i of intercropping term as density 5 x j m,

$Q_{i,j}$ - NPV of crops in i year of intercropping term as density 5 x j m.

2) Benefit-Cost Rate:

$$BCR = \frac{NPV}{C_{11,40}-C_{8,40}-C_{8,20}-C_{6,20}+C_{6,10}} \times 100\%$$

where:

$C_{i,j}$ - Present value of total cost in i year of intercropping term as density 5 x j m.

3) Land Expected Value:

$$LEV = NPV \times \frac{(1+i)^t}{(1+i)^t-1}$$

where: t = 11, i = 0.08.

The optimum model (A) was calculated with above formulae as shown in Tables 9, 10.

Practice of two-storeyed management and rotation on the same stretch of land -

The model of density 5 x 40 m and rotation of 11 years can meet the four objectives to maximal extent. From the above analysis of intermediate cutting the density to crop yield is less than 10%. It is important to determine whether trees can be continuously planted after intermediate cutting, to make it a two-storeyed system, so as to shorten the intercropping period and increase benefits. According to the result, the effect to the relative wheat yield is less than 10% as the density of 5 x 20 m before year 8 and this density could be maintained till year 8. The effects of trees to growth of crop primarily depended on the size of the crown and crown grows larger with increasing age. According to the process of tree growth, the size of crown of two even-aged trees is roughly equal to the sum of crown of an older tree. The sum effects of a 12-year old tree and a 6-year old tree to crop yield are equal to that of two 9-year old trees. According to this principle, we can adopt the density of 5 x 20 m and maintain it in the two-storeyed management. The difference between two age-groups is six years, cutting cycle is six years, rotation is 11 years. As the first age-group enters the age of harvest - year 11 (12-year old), the second age-group is just in year 5 (6-year old). The effect of wheat relative yield in wheat is within 10% hence the maximum benefit would be obtained. It is calculated as follows:

1) Net Present Value:

$$NPV = (Q_{8,20} - Q_{2,20} + \frac{L_5-L_6}{2} \times 100 \times \frac{(1+i)^6-1}{ix(1+i)^6} + \frac{P_{11}x50}{(1+i)^6} - 3 \times \frac{50}{1+i}) \times \frac{11}{6}$$

where: $Q_{8,20}$ is NPV of crops as the density of 5 x 20 m remains from year 3-8. Under two-storeyed management, the effect of the crown on two-aged groups to crop yield from 4-11 years is the same as even-aged trees of 3-8 years. $[(L_5 + L_6)/2 \times 100] \times [(1+i)^6 - 1]/[i(1+i)^6]$ is the value of foliage during year 5-11 of the intercropping term. The yield of leaves for 11 years of the intercropping term is shown as a cyclical change and its average value per year is roughly equal to that between year 5 and 6 of the intercropping term. P_{11} is the sum of value of *Paulownia* timber, branch and stock per tree in year 11 of the intercropping term. 3 x 50/(1+i) is the present value of establishment cost as the density of 5 x 40 m.

2) Benefit-Cost Rate:

$$BCR = [\frac{NPV}{C_{EX}\frac{1}{1+i}x100+C_{c}x\frac{(1+i)^{11}-1}{i(1+i)^{11}}}] + 1 \times 100\%$$

3) Land Expected Value:

$$LEV = NPV \times \frac{(1+i)^{11}}{(1+i)^{11}-1}$$

Through the above calculation, the optimum model (B) is obtained (Table 12).

Table 11. Sensitivity analysis of optimum model

			Optimum Model A			Optimum Model B		
Model	ID	%	NPV (US$/ha)	BCR (%)	LEV (US$/ha)	NPV (US$/ha)	BCR (%)	LEV (US$/ha)
1	BM	0	9024.73	342.84	15801.89	9520.64	360.31	16670.20
	DT 8%	+2	8009.91	336.30	12332.31	8628.69	358.98	13285.00
		-2	10227.99	349.73	21613.96	10531.72	360.98	22255.81
	FY	+10	9904.94	366.52	17343.09	10442.00	385.51	18283.46
		-10	8144.52	319.15	14260.68	8599.27	335.12	15056.92
	FP	+10	9904.94	366.52	17343.09	10442.00	385.51	18283.46
		-10	8144.52	319.15	14260.68	8599.27	335.12	15056.92
	CC	+10	8664.91	312.57	15171.86	9154.41	327.88	16028.95
		-10	9384.56	379.59	16431.93	9886.87	399.83	17311.45
	PP	+10	9348.08	350.74	16368.06	9870.37	369.44	17282.56
		-10	8701.38	334.88	15235.71	9170.90	351.16	16057.82
2	BM	0	8638.34	359.47	15125.33	9169.26	380.39	16054.95
	DT 8%	+2	7655.73	352.05	11787.00	8308.08	378.84	12791.38
		-2	9804.14	367.30	20718.27	10145.48	381.22	21439.60
	FY	+10	9441.19	383.59	16531.09	10016.06	406.28	17537.66
		-10	7835.48	335.35	13719.56	8322.40	354.49	14572.14
	FP	+10	9441.19	383.59	16531.09	10016.06	406.28	17537.66
		-10	7835.48	335.35	13719.56	8322.40	354.49	14572.14
	CC	+10	8317.23	327.85	14563.09	8842.39	346.22	15482.62
		-10	8959.44	397.84	15687.57	9496.07	422.00	16627.18
	PP	+10	8961.69	368.23	15691.51	9519.00	390.56	16667.33
		-10	8314.99	350.65	14559.16	8819.52	370.18	15442.57
3	BM	0	11555.94	326.34	20233.92	12538.38	348.45	21954.12
	DT 8%	+2	10338.06	322.15	15916.80	11383.60	347.70	17526.55
		-2	12992.98	330.77	27456.99	13845.68	348.57	29259.31
	FY	+10	12828.19	351.26	22461.57	13902.94	375.49	24343.41
		-10	10283.68	301.42	18006.25	11173.87	321.42	19564.93
	FP	+10	12828.19	351.26	22461.57	13902.94	375.49	24343.41
		-10	10283.68	301.42	18006.25	11173.87	321.42	19564.93
	CC	+10	11057.19	297.30	19360.63	12030.79	316.95	21065.36
		-10	12054.68	361.67	21107.19	13046.02	386.86	22842.98
	PP	+10	11879.28	332.14	20800.07	12888.17	355.09	22566.59
		-10	11232.59	320.52	19667.75	12188.64	341.81	21341.75

Table 12. Compared with non-intercropped land.

Model	NPV		BCR		LEV		WRY
	US$/ha	+%	%	+%	US$/ha	+%	%
Model 1	9520.64	158	360.31	135	16670.20	158	90
Control	5992.87		266.55		10493.24		100
Model 2	9169.26	170	380.39	142	16054.95	170	90
Control	5364.67		267.07		9393.29		100
Model 3	12538.38	136	348.45	122	21954.12	136	90
Control	9204.01		284.54		16115.80		100

Sensitivity Analysis of Optimum Model -

Sensitivity analysis is used to measure the effects of various indeterminate factors as they change to each evaluation criterion of the optimum model. Meanwhile, the criterion used in case of each optimum model is compared with each other. Finally, the best one was chosen. There are many indeterminate factors. Here, only some significant economic factors are studied, i.e., yield of crops, price of farm-products, comprehensive cost of intercropping land and price of *Paulownia* products. While only one factor was allowed to be variable within the extent of 10% each time. The corresponding change of criteria of each model used are shown (Table 11). The model (B) is much better than model (A) (Table 11). Whatever factor is changed, all of the criteria of model (B) are greater than that of model (A). In the meanwhile, the effect and extent of each factor changing are clearly shown in Fig. 4. The criteria of different factors have different sensitivities. These factors are discount rate, yield and price of crops, comprehensive cost, and price of *Paulownia* products. Among them, the effect of discount rate is most important, the price of *Paulownia* the least, the yield of crops is the same as its price. However, all the indeterminate factors change as long as they are within the extent of 10%, and the model (B) serves as optimum.

Benefits of Intercropping Compared with Non-intercropping - As an optimum model (B) of PCI, it can make use of land resources at the maximal limit and also meets the requirements of the four objectives, solves the problem of demand for food, timber, fuel and fodder. It increases farmers' income and improves the level of the farmers' life in the poor regions. Therefore, this model is more suitable for the Chinese countryside and the other developing countries to expand in large areas, so as to improve the prosperity and development of rural economies. It also answers these questions when compared with control land (Table 12). The increase of income and the profitable level of intercropping land is much more than that of non-intercropped land and the decrease rate of wheat yield is less than 10%. In comparing the three models, according to the results of analysis, it is clear that model 3 is the best, model 1 is the second and model 2 is the last. As the species planted in the three models were different, it is important to choose proper crop species in accordance with the local demand and social conditions.

A Preliminary Study on the Animal Fauna in Intercropped Area with *Paulownia*

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ABSTRACT

This paper deals with the animal population in intercropped areas with Paulownia. Macrosiphum and Cicadella species were abundant besides aphids, lacebugs, sawflies, spiders, scale insects, ants, beetles and others. There were no differences in fauna between various intercropping densities. Other variations are mentioned.

Introduction

Paulownia-crop intercropping in the plain and low mountain areas of China has been developed rapidly during the past ten years with an intercropping area of more than 6.7 million ha. The fauna in *Paulownia* intercropping area has not been studied to-date. To provide the parameters for the best intercropping model, we investigated the animal species and individual quantities in various intercropping densities and the results are summarised in this paper.

Methods

Investigations were conducted in five experimental *Paulownia* intercropping densities (age of *Paulownia* 8), namely, 5 x 6, 5 x 10, 5 x 20, 5 x 40 m and control field (no *Paulownia* planted), at the over-wintering period (January) and mature period (May) of wheat, and the growing period (July) and mature period (September) of cotton. Sampling was found at five layers in every intercropping density, e.g., (1) crown of the tree; (2) trunk of the tree; (3) upper layer of the crop; (4) crop and (5) underground layer. The species and quantity of animals collected and classified are recorded.

The scissors-bag method was used in the investigation on the crown of the tree: Twenty trees were sampled and two branches of each were investigated in one sampling field. The size of the bag was 30 cm (entrance diameter) x 60 cm (length) x 16 cm (bottom diameter). Animals under 2 m near the tree trunk were recorded. The insect-catching net was cleared 200 times to investigate the upper layer of the crop and net size was the same as the bag. Twelve to sixteen samples were taken separately in layers of the crop and the soil and the size of the sample area was 50 cm (length) x 50 cm (width) x 25 cm (depth of underground layer). The sample areas of the underground layer were 0, 2.5, 5 m respectively away from the tree and center of two *Paulownia* rows (e.g., 10, 20 or 25 m far from the tree). After the specimens were classified, the data were analysed.

Results and Analysis

Components of the Fauna -
Investigation of six sample fields showed that there were 35 families belonging to ten orders of insects, nine families belonging to two orders in *Araneida* class and one family in *Oligochaeta* class. More than 60 species of animals were recorded.

Differences of Animal Species and Quantity in Various Seasons -
Animal quantities of one to four layers during the overwintering period were very small due to low temperatures. The underground animals were mainly earthworm and small numbers of larvae, pupae of insects, grubs and ants. They lived in soil 5-30 cm depth. In May, *Macrosiphum granarium* accounted for more than 90% of the total animal

Table 1. Fauna at different intercrop densities and seasonal variations. Dangshan County, Anhui Province, May to September, 1989.

Intercrop density (m x m)	Season	Species	Quantity	Quantity of Pests	Quantity of enemy insects	Remarks
5 x 6	May	7	66	12	49	Open ground
	July	18	424	416	4	▲
	Sep.	-	-	-	-	
5 x 10	May	11	57	16	38	
	July	18	121	110	9	Open ground
	Sep.	16	108	70	37	
5 x 20	May	9	93	17	70	
	July	20	423	403	14	
	Sep.	24	114	69	40	
5 x 40	May	9	78	20	52	
	July	19	833	790	37	
	Sep.	25	89	49	38	
5 x 50	May	11	94	19	71	
	July	18	463	383	51	
	Sep.	23	119	60	53	
Control	May	7	31	7	21	
	July	13	73	37	42	
	Sep.	12	43	31	7	

Notes: Species implied animals of 1-4 layers, not including ants, aphids and spiders.
Quantity did not include ants, aphids and underground animals.
▲ = uninvestigated for pesticiding.

quantity and ranked first of the animals in crowns of trees. The other animals were ants, inchworms and a small quantity of shieldbugs, spiders, scale insects and beetles. The main animals in crop layer were aphids, lacebugs, sawflies, spiders, syrphidae insects, Braconidae insects, Chrysopidae insects and ants. Those of soil were mainly grubs, worms and ants. *Cryptothelae variegata*, the main pest of *Paulownia*, was in the young larval stage in July. Its quantity accounted for the greatest amount of animals in the tree crown layer. The second most abundant one was *Cicadella viridis* (L.). In September, the main animal in the crown of trees was also *C. variegata*. The others were ladybugs, stinkbugs, Chryspidae insects, ants, spiders, etc. The animals in the crop layer were primarily the beneficial and harmful insects of cotton in July and September, e.g., *Aphis gossypii*, Glover, stinkbug, Chrysopidae insect and ant. There were also some *C. variegata* insects that fed on leaves of cotton. Table 1 shows that there were more animals in July and September than in May, and animals in July were more abundant than those in September. The natural enemy/pest ratio in May was highest, while in July it decreased to the lowest point. The reason was that pests were most abundant in July and fauna was in unstable stage (Table 1).

Fauna in Various Intercropping Models - Differences in animal species and quantities -

Analysing the results of various periods (see Table 1) showed that animal species and quantities increased markedly after intercropping. These animal species were mostly those that fed on or lived with *Paulownia*, e.g., *C. variegata*, Eucleidae insect, tussockmoth, Sphinx, beetle and parasitic wasp. Ants and spiders increased near the tree trunk. Most of these animals had a predatory effect on other animals and they were beneficial to the crop and to *Paulownia*. *Paulownia* in crop fields provided food and living sites for some animals, and also enriched the fauna in crop fields.

Table 2. Comparison of fauna in the crown of trees with different intercropped densities. Dangshan County, Anhui Province, 1989

Item	5 x 6 m			5 x 10 m			5 x 20 m			5 x 40 m			5 x 50 m		
	May	July	Sep.	May	July	Sep.	May	July	Sep.	May	July	Sep.	May	July	Sep.
Animals	196	292	-*	264	101	97	405	270	79	578	581	63	28	269	93
Cryptothelea variegata	0	254	-*	0	21	30	0	174	34	0	486	26	0	121	32

* *Uninvestigated for spraying of chemicals*

Variation of fauna in the crowns of trees - Table 2 illustrates the quantity of animals and *C. variegata* in the crowns of trees. The change in the quantity of aphids influenced the animal quantity in the crowns of trees. *M. granarium* fed on wheat which explained the close relationship between the quantity of aphids in the crowns and those in wheat. Table 2 shows the differences between the animal quantities and densities. No regular pattern was present because of the activity of aphids. The principle animal in crowns was *C. variegata* in July and September. *C. variegata* was in young larval stage and most abundant in July and its quantity in various intercropping densities were close in September. There was no clear relationship between *C. variegata* and intercropping density.

Influences on underground fauna after intercropping - In fields of cotton-*Paulownia* and wheat-*Paulownia* intercropping, the underground animal species were mainly grubs, worms, ants and larvae or pupae belonging to Diptera, Lepidoptera and Homoptera. Table 3 illustrates statistics on the underground fauna of five intercropping densities. It is clear that the animal quantity next to tree trunks was greater than those at 2.5 m from the tree. The reason was that there were more ants beside tree trunks due to less interference from ploughing. Roots provided food and attracted some animals and grub quantities were related to the roots in the field. In July, wheat was cut, and cotton was very young while the tree roots were enormous. So the quantity of grubs beside the tree trunk was greater than those at 2.5 m away from the tree. The quantity of earth worms related closely with the fertility of the soil. The reason for larger quantities of worms beside tree trunks in May and July can be attributed to the greater humus accumulation. Table 4 illustrates the results of investigations on 5 x 10, 5 x 20, 5 x 40 and 5 x 50 m sample fields. It can be seen that there were no distinct differences in the underground animal quantity between 2.5 m and 5 m from the trees. There were also no differences between quantities of grubs and worms. Through the analysis on Tables 3 and 4, we can see that the influence of *Paulownia* on underground fauna was mainly restricted to an area of 2.5 m from the trees.

Conclusion

The species and quantities of animals increased when a crop was intercropped with *Paulownia*, especially those animals that fed on *Paulownia* or lived with it, e.g., *C. variegata*, Eucleidae insect, inchbug, Sphinx, beetle and spider. *Paulownia* provided active sites for many natural enemies and suitable conditions for their survival. There were no distinct differences in fauna between various intercropping densities. There were more animals in soil under 2.5 m from the tree than those beyond 2.5 m. The reason was that roots and different soil conditions near the trees provided suitable environment for the animals. The primary animals in *Paulownia* intercropping are were aphids and *C. variegata*. The others were grubs, leafhoppers, stinkbugs, ladybugs, Chrysopidae insects, ants and

Table 3. Comparison of underground fauna at different distances from trees. Dangshan County, Anhui Province, 1989,

Item	0 m			2.5 m		
	May	July	Sep.	May	July	Sep.
Total	157	206	73	62	150	41
Grubs	27	80	6	18	22	5
Worms	85	106	45	33	104	30

Table 4. Comparison of underground fauna between different distances from trees. Dangshan County, Anhui Province, 1989.

Item	2.5 m			5.0 m		
	May	July	Sep.	May	July	Sep.
Total	44	134	33	45	122	31
Grubs	13	22	3	17	14	3
Worms	25	92	25	15	100	20

spiders. The change of fauna depended on changes of *C. variegata*, leafhoppers, aphids and Chrysopidae insects.

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Investigation on *Paulownia*-medicinal Plants Intercropping Model Systems in Bozhou

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ABSTRACT

Bozhou, located in the northwestern Huibei Plain of Anhui Province, is abundant in production of Paulownia and Chinese medicinal plants. As an improvement of agriculture and forestry, Paulownia-medicinal species were grown as intercrops. The suitable growth condition, spacing, selection and combination of species/varieties, with the resulting economic benefits are discussed. A recommendation for further extension of the intercropping model is also presented.

Introduction

Bozhou is in northwest of Huibei Plain of Anhui Province, north latitude 33°24'-34°05', east longitude 115°32'-116°01', belonging to warm temperate zone. The annual mean temperature is 14.5°C, annual rainfall 807 mm, and number of no frost days is 209 per year. The soil is of alluvial material deposited by the Yellow River flowing south. The soil is of two kinds: one moist soil mainly distributed in the area close to the two banks of the river, and the other is Sajang meadow soil.

Bozhou is the birthplace of the famous ancient Chinese doctor Hua Tuo. It is also one of the "Four Main Distributing Centers of Chinese Medicinal Materials", and a major production area of *Paulownia*, and there is a long local history of both. Based on the development of fast-growing native species, an integrated shelter belt system in farmland was recently established. The forest covers 23.24% of the total land. The area of fast-growing *Paulownia* plantations and crop-*Paulownia* intercropping reached up to 7,000 ha in the county. There are about 5 million *Paulownia* trees planted and the county has become an important production base for *Paulownia* timber with 25% of the total output value for the county. The cultivation of some traditional medicinal plants such as herbaceous peony, Bozhou chrysanthemum, aster and bafflower, etc. is increasing very fast. The area for planting herbaceous peony in the last three years increased up to 3,500 ha. The price for the traditional medicinal materials is rising, and the enthusiasm for planting medicinal plants has been great. Therefore, communities of forest tree-medicinal plant intercropping systems have been developed as a new farming system. Through long-term practices, forest tree-medicinal plant intercropping seems to be a promising agroforestry system with high ecological and economic benefit for further extension.

Suitable Site Conditions

The *Paulownia*-medicinal plant intercropping is mainly distributed along the Guohe River and its branches. The moist soil of the region can be divided into several types: loose sandy - sandy - sandy/salt - deposit soil. The growth comparisons of *Paulownia* and herbaceous peony in different soils are listed in Table 1 and 2. At the higher altitude (32-42 m) with lower ground water level (usually under 3-5 m), *Paulownia* and herbaceous peony can grow on various types of soil. But their growth performances in different types of soil vary. The sandy soil is most suitable for *Paulownia* growth, sandy/salt soil and red deposit soil are fairly suitable, and the deposit soil is least suitable. The volume growth of *Paulownia* is 30.6% and 22.2% higher in the first two types of soil than in deposit soil.

The roots are somewhat succulent in *Paulownia*

Table 1. Growth comparison of *Paulownia* in different soils*.

Soil	Sandy Soil		Sandy/Silt Soil		Red Deposit Soil		Deposit Soil	
Annual Growth	Absolute Value	%	Absolute Value	%	Absolute Value	%	Absolute Value	
DBH(cm)	3.0-4.5	33.9	2.5-4.5	125	2.8-4.3	127	2.2-3.4	100
Height (m)	2.0-3.6	22.4	2.0-3.4	120	1.8-3.2	111	1.5-3.0	100
Volume ($10^{-2}m^3$)	1.9-2.8	131	1.8-2.6	122	1.5-2.6	114	1.4-2.2	100

*Calculated from the data of 27 sample plots, and they are 3-5 years old stands.

and herbaceous peony. They prefer deep, loose, moist and well-aerated soil. The aerated soil condition influences the growth of both the species. Compared to *Paulownia*, herbaceous plant needs more fertile soil. So it is necessary to strengthen management of water and fertiliser for a good harvest which also improves the growth of *Paulownia* trees. The soil structure and depth of underground water is very different among the different soil types in this region. The growth of *Paulownia* and herbaceous peony planted in the deposit soil performed very differently. Sajang meadow soil is usually distributed in low places, with high underground water level which is not suitable for growing *Paulownia* and herbaceous plants.

Rational Planting Spacing

In *Paulownia*-medicinal plant interplanting system, the important factor that influences the output is the planting spacing of *Paulownia*. A rational relationship between upper tree layer and interplanted shrubs should be properly managed. Presently, the planting spacing of the interplanting systems are varied and the interplanting is narrow. As *Paulownia* grows, the crown becomes larger and sheltered area becomes bigger. If thinning is not done at the appropriate time, it causes variation between individuals with unstable yield. The data listed in Table 3 shows rational planting density.

From the same table, we can find that *Paulownia* stands with different planting spacing have different growth performances. The 4-year old stands with spacings of 3 x 4 and 4 x 5 m are 12.5-24.4% higher in DBH growth and 22.9-83.6% higher in volume than those in 2 x 2 m stand. The narrow density is good in early stages because of high total volume accumulation, but narrow spacing usually restrains the growth of individual trees. The successive growth rate of the stand with 2 x 2 m planting spacing is reduced at five to six years after planting. *Paulownia* needs strong illumination. In 4-year old stands, the obstructed trees account for 10-15% of the total. The plants that grow under the crown canopy have crooked trunks, inclined crowns and some even died. The suitable planting spacings for *Paulownia* woodlots is 3 x 4 - 4 x 5 m. In this way, the cash crops can be interplanted under the woodlots and the trees can be for purlin at around 5-6 years old.

The planting spacing also effects the growth of interplants. The output of interplanted herbaceous peony under 5-year old *Paulownia* stands with spacing 4 x 5 m (canopy cover rate 0.8-0.9) is one time lower than that in the stand with spacings of 5 x 20 m. In herbaceous peony planted under the shelter of *Paulownia*, the above ground part performed as well as that in open field. Because of high water content, the dry material of the root tubers was 40-60% less than that of those planted in open field. The fast-growing period of *Paulownia* crown is from two to five years after planting, after that it grows slowly. *Paulownia* spreads its crown by two forked branches, of which, one is strong and the other weak which withers easily. Therefore, the early crown is thinner and sparser, and the degree of penetration of sunlight through the crown is high. According to the measurements, the crown diameter of a 5-year old *Paulownia* tree is 4.5-5.5 m, covering an area of 4 m^2, 8-10-year old tree's crown diameter is 7-8 m, covering an area of about 6 m^2. So it can be estimated that the shaded land accounts for 20% of the total at 5th year and 30% at the 8th-10th year in a 5 x 10 m stand. The appropriate planting spacing

Table 2. Growth variations of herbaceous peony grown in different soils*.

Soil	Sandy Soil	Sandy/Silt Soil	Red Deposit Soil	Deposit Soil
Stem Number Per Ha	27,000	21,675 - 27,000	25,500	30,600 - 32,400
Output Per Stem (kg)	1.25	1 - 1.25	0.65	0.35-0.4
Output Per Ha (kg)	33,750	21,675 - 33,750	16,575	10,710 - 12,960
%	260.4	167.5-260.4	127.9	100

**Calculated from the data of nine sample plots*

of *Paulownia* for interplanting is 5 x 30 - 5 x 40 m. The existing plantations planted at spacing of 5 x 20 m, can be thinned (50%) at five to six years after planting. At the same time, young trees should be replanted after thinning, and another 50% can be thinned and replanted again. In this way, a permanent utilisation system can be sustained.

Selection of Species and Cultivars

For *Paulownia*-medicinal plant interplant- ing, the selected *Paulownia* species should have the characteristics of a sparse crown, with good trunk form; the suitable species Lankou *Paulownia* (*Paulownia elongata*). The selected medicinal plant species are usually the traditional ones with large market demand of economic value, including herbaceous peony, Bozhou chrysanthemum, etc. with many cultivars. Herbaceous peony has four cultivars named "Xiantiao", "Pubang", "Jizhao" and "Macha". Of which "Xiantiao", also called "Benhuazi" locally, is of high quality (long twig, abundant starch, solid texture and pure white colour) and a high-yielding cultivar, but the production rotation is relatively long. It usually needs four years to harvest after planting. "Pubang" also called "Zhaohuazi" locally, has the characteristics of short twig, loose texture and a quality inferior to "Xiantiao", but is high-yielding with short production rotation of 28 months before harvest. Considering both the quality of products and short term returns, both kinds of cultivars are cultivated in proper proportions.

Interplanting Model Systems

Woodlots Around Villages -

The management objective of this type of interplanting system is to produce *Paulownia* purlin for local construction and by-products from the herbaceous peony and other cash crops. The appropriate planting spacing of *Paulownia* trees is from 3 x 4 to 4 x 5 m, and the suitable spacing of herbaceous peony is 0.5 x 0.67 m. With this condition, the *Paulownia* trees can reach the standard of purlin production (3.5-7 m in length and 12-16 cm in diameter in top end) in five to seven years. On a good site, only 4-year old *Paulownia* can be used for purlin. Herbaceous peony can be harvested at five years after planting. For effective use of land resources and quick returns, in the first three years, agricultural crops such as broad bean, garlic, taicai, ginger and other vegetables can be intercropped under the system. When the shelter effects of *Paulownia* are more apparent, herbaceous peony plants are planted widely and the yields of agricultural crops start to decline. In this type of interplanting system, the volume accumulation of 5-year old *Paulownia* stands is 10.5-13.5 m^3/ha and output of herbaceous peony is 1,575-2,160 kg/ha. Calculated according to the market price, the annual output value is up to 8,520-11,360 Chinese Yuan (RMB)/ha/yr, two to three times more than common crops.

Intercropping in Farmland -

The management objective of this intercropping system is mainly for medicinal material production and producing commercial class *Paulownia* timber. The so-called "engraving timber", that is 6 m in length with 40 cm in diameter at small end, is much more valuable than common *Paulownia* timber. The price of "engraving timber" is three to four times of that of the common timber. The planting spacing of *Paulownia* trees is 5 x 20 - 5 x 40 m, and the spacing of herbaceous peony is 0.5 x 0.67 m. The rotation of *Paulownia* is ten years, only five years for herbaceous peony, i.e., two crops of herbaceous peony can be planted in one rotation of *Paulownia*. In the first five years herbaceous peony is planted in a belt with a width of 4-8 m along the *Paulownia* rows, and another belt with a width of 16-32 m between the *Paulownia* rows is used for agricultural production

Table 3. The growth performance of *Paulownia* woodlots in different planting densities*.

Soil types	Age (yr)	Spacing (m)	DBH (cm)	Height (m)	Volume (m^3) Absolute Value	Volume (m^3) %	DBH Distribution (%) >15 cm	DBH Distribution (%) <10cm
Sandy Soil	4	2 x 2	13.6	8.7	0.061	100.0	37.0	12.0
	4	3 x 3	14.5	9.0	0.075	103.0	45.0	6.5
	4	3 x 4	15.3	10.6	0.096	157.4	67.0	2.1
	4	4 x 4	16.4	10.4	0.112	183.6	75.0	0
Sandy/ Silt Soil	4	2 x 2	13.6	9.6	0.070	100.0	32.0	15.0
	4	2 x 3	14.9	9.6	0.084	120.0	39.0	8.0
	4	3 x 4	15.8	8.7	0.086	124.9	78.0	2.0
	4	4 x 5	16.9	9.9	0.111	158.6	79.0	0

**Investigation places: Nineteen Li District, Eighteen Li District and Dayang District along Guohe River, Bozhou.*

of cotton, etc. During the second five years, the width of the herbaceous peony belt is extended to 8-12 m. In this way, the width of the belt for agricultural crops is only 12-28 m, but the total yield of agricultural crops is still higher than that in the non-intercropped field because of the protective function of shelter belt. The present problem is that the planting spacing of *Paulownia* is too narrow (5 x 10 m). Nearly 20% of the total land will have a negative effect on the yield of intercrops. Another problem is that the herbaceous peony is not suitable for continuous cropping due to harmful insects such as grub, cutworm, etc. The shifting cultivation of herbaceous peony and wheat can solve this problem. In continuous cropping, the insects can be eradicated with mixed powder of 6% "BHC", bean cake, maize powder or 22.5 kg "BHC" broadcast in the field at site preparation.

The DBH of *Paulownia* trees in 5 x 20 m planting spacing can reach 18.0-22.0 cm in five years with average volume increase of 1.785-3.045 m^3/ha/yr. The yield of first crop of herbaceous peony is 11,700-16,570 kg/ha, and under good site condition (fertile sandy or sandy/silt soil) go up to 30,000 kg/ha. This yield increase indicates the improved microclimate effect of shelter belts. The average output value of herbaceous peony is up to 7,950-22,950 COY/ha/yr, i.e., two to six times of that of agricultural crops with the maximum of 150,000 COY/ha from a crop of herbaceous peony (five year rotation) according to local sources. The local farmers use *Paulownia*-medicinal species intercropping system to make considerable money and get high interest from the "Green Bank".

Conclusion

Paulownia-medicinal plant intercropping is a new farming system. It involves efficient utilisation of native germplasm and other natural resources. Through this kind intercropping, agriculture, forestry and medicinal crops are combined. The technological essentials for this kind intercropping system development are as follows:

i) *Suitable site condition:* The soil must be deep, loose, damp and well aerated. The sandy and sand/silt soil are best and red deposit soil is suitable for intercropping system. The waterlogged lowland and Sajang meadow soil with heavy clay is not suitable.
ii) *Rational planting spacing:* The appropriate planting spacing of *Paulownia* is 3 x 4 - 4 x 5 m for woodlot type and 5 x 30 - 5 x 40 m for farmland type.
iii) *Five propagation materials:* The suitable *Paulownia* species is Lankou *Paulownia* (*Paulownia elongata*) with thin crown and good trunk form. High quality and high yield cultivars of herbaceous peony should be selected for the system.
iv) *Rational structure:* With the changes of time and space, the structure of the intercropping communities should be controlled by various management measures, such as pruning, erasing buds, etc. that have a positive effect for crop growth.

Intercropping With *Zizyphus Zuzuba*- a Traditional Agroforestry Model

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ABSTRACT

Zizyphus zuzuba var. spinosus adopts to sandy clay soils. Its leaves and branches are small, sparse and leaves emerge late and fall early. It is a successful agroforestry species in Hebei and certain areas of Shandong. The appropriate planting model of jujuba is with spacing of 3-4 x 15 m, 5-6 m in north-south orientation, and combining with "high-low-high" or "high-low-middle-low-high" crops. Energy utilisation ratio is 77% higher than that in monoculture. It produces 4,500 kg/ha dried fruits annually, three times higher in the intercropping system than in monoculture.

Introduction

Zizyphus zuzuba var. *spinosus* is an indigenous species of China and the trees grow well in temperate climate zones. It is mainly distributed in the middle-low reaches of Yellow River in Henan, Shanxi and Shandong provinces, stretching from east longitude E. 76°-124°, north latitude N. 23°-42°. This species was disseminated to West Asia over 2,000 years ago, to India in the 1930s and to Europe in 1937. It is a very desirable agroforestry species, producing nutritious and delicious fruits and medicinal materials. The well-known ancient "Material Book of Medicine" (Materia Medica) recorded that dried jujuba fruits nourish five internal organs (heart, liver, spleen, lungs and kidneys), cure cough, etc. and "prolong life". The processed dried jujuba fruits contain 73% sugar and 3.3% protein.

Main crop species grown with jujuba in China are wheat, corn, soybean, cotton and vegetables. The agroforestry system has been better developed recently with 200,000 ha in the whole country and the fruits from inter-cropping system account for 65% of total supplies throughout China.

Species Combination and Structure of Jujuba-Crop Intercropping

Orientation -

The growing season of *Zizyphus zuzuba* is from May to October and the sparse canopy allows most light through but degree of light penetration depends on orientation. Oriented north-south, the percentage of radiation penetrating is 51%, which is much higher than 30% (north side) and 34% (south side) of the west-east orientation. Light durations are much different between two orientations. At 3.5 m distance from 5 m height west-east oriented jujuba trees, light penetration was reduced by six to eight hours which effected crop yield. The yields of the two crops of wheat and corn were 7.7-15.7% and 30% lower in W-E oriented than S-N oriented. The fruit yield was 10-15% lower in former than in latter. So S-N orientation was better in jujuba-crop intercropping system.

Spacing -

At distance of 4 m from trees, light penetration was differently affected; light index was 0.80-0.87 at 2 m from trees in S-N orientation, while it was 0.96-0.98 at 4 m, and 1.002 at 6-10 m. It was noted that rows' interval of 8 m was the minimum distance. Light duration was also related to rows' distance. At 2 m distance, S-N oriented rows' radiant hours were 8 hours and 30 mins, 7 hours and 45 mins, 5 hours and 47 mins each for 18, 15, 10 m rows' interval and 57%, 52%, 39% of that in open field respectively. The 15 m interval was accepted as better spacing and crops are most shaded in 10

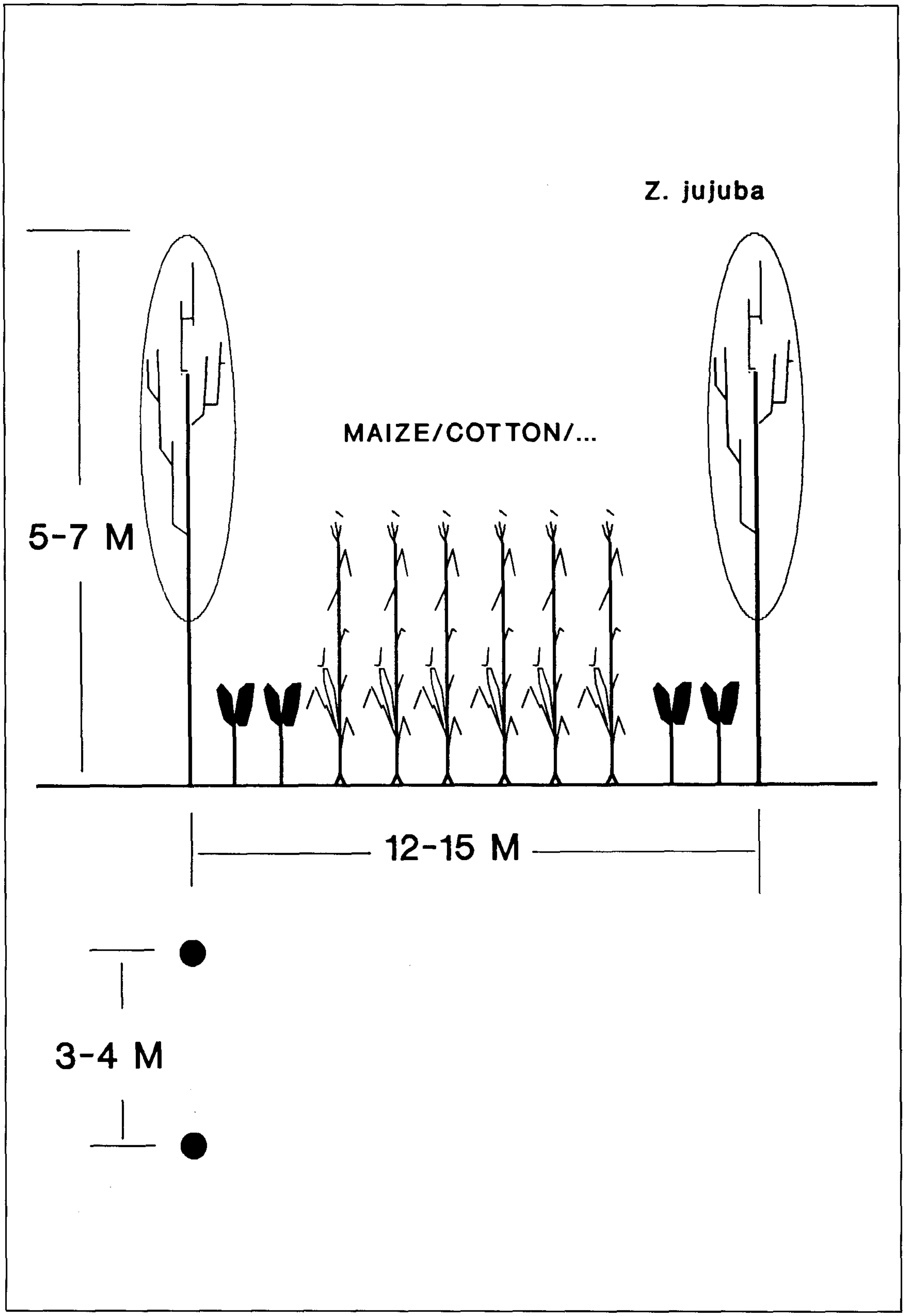

Fig. 1. *"High-low-middle-low-high" planting model of jujuba-crop intercropping.*

m intervals. There is not much difference in microclimatic changes and crop yield between 15 m and 18 m intervals.

Z. zuzuba has a small canopy with a range of 3.5-4.5 m. At 1.2 m from the canopy, 15,000 lux light intensity reached ground for 11 hours. Daily integral light intensities achieved 19,884 x 10^5 lux which was 66% of that in open fields. The best spacing was 3-4 m.

Trunk Height and Crown Density - In pure *Z. zuzuba* stands, low trunks are easy to manage and output is high. However, it needs a high trunk in intercropping system so as to not affect crops. It was stated that 1.4 m under crown height was suitable for the production of both fruits and crops. It was recorded that during the growing season light intensity was 15,000-48,000 lux with higher trunks and it was lower than 20,000 lux under canopies of 1.2 m high.

Intercropped Crops -

Different distances from hedgerows have various shading degrees which affect crop growth differently. In the model of 4 x 15 m spacing with crown range of 5 m; under canopy height of 1.4 m, light intensity under the tree crown during summer was only 15,000-48,000 lux which accounted for 27-59% of those in open fields. The suitable summer intercrops should have a short, shallow root system; shade-tolerant crops like soybean, mung bean, day lily, etc. At a distance of 2 m from hedgerows to the tree crown, the duration of direct light was 1.5 hours shorter than in open field. The light intensity during 9 am to 3 pm was 48,000-80,000 lux which accounted for 60-100% of open field. The intercropped crops should have high light compensation points such as cotton, millet, etc. Far from tree hedgerows for more than 2 m, where the microclimate conditions are similar with open fields, inter-cropped tall crops can be corn, sorghum and others.

The above listed crops are suitable for growing in the jujuba-crop intercropping system in summer. In winter, when the trees are bare and dormant, the microclimatic conditions are almost the same in the open field. Winter wheat is the most appropriate crop. Wheat turns green when tree leaves having not yet emerged, light intensities in the intercropping field are 6,500-92,500 lux which is 96% of that in open fields. *Z. zuzuba* leaves emerge when wheat reached the jointing stage (26 April). The newly emerged leaves still allow 96% of light to penetrate the canopies. Wheat flowered and filling stage started as trees also grew. The light intensity was 20,000-70,000 lux which was more than enough light needed by wheat (20,000-30,000 lux). Hedgerows also protected wheat from hot, dry, strong winds. It may be concluded that the desirable model for arrangement of crops at different distances from hedgerows around year can be "high-low-high" or "high-low-middle-low-high" forms (Fig. 1).

The Ecological and Economic Benefits

Jujuba-crop intercropping has over 600 years' history in China. This intercropping pattern has good ecological and economic benefits adopted by the local farmers over a long period of time.

Concerning the ecological effects, the temperature in intercropped field was 0.5-1.0°C lower with 6-8.2% higher humidity. Nearly 64% reduction in wind speed during the hot, dry strong wind season, that protected the crops efficiently. Under the hot, dry wind conditions, the yield of wheat increased by 5-10%. Compared with pure culture, jujuba-crop intercropping has a more effective use of natural resources in many ways. The high percentage of energy utilisation of different cultivation methods are 62.5-64.6% in pure culture of one crop per year system, 100% in pure culture of two crops per year system, 141% in three crops per year system, and 177% in jujuba-crop intercropping system.

The annual economic profits are 15,755, 8,402, 6,034 and 2,248 Chinese Yuan (RMB) per ha respectively in jujuba-crop intercropping systems with row distances of 7, 15, 21 m over the pure crop culture system. The figures indicate that jujuba-crop intercropping is very successful and wide extension of this farming system will aid agricultural development in China.

Cultivation and Intercropping with Shrubby Ash *(Fraxinus)*

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ABSTRACT

The paper deals with morphological and ecological properties and growth patterns of shrubby ash trees. The cultivation techniques of trees with intercropping systems including species combination, disposition, etc. and economic benefits are presented in this paper.
Key Words *Shrubby ash, intercropping, ecology, economics*

Introduction

Ash (*Fraxinus* sp.) are deciduous trees or shrubs of the family Oleaceae. They put out buds very easily and shoots are very flexible. Usually, ash is cultivated as shrubs to get shoots. So it is called "shrubby ash" which is very useful. It can be planted to block wind and sand. The stems can be woven into baskets which are elastic and tough. Leaves are good for fodder. Through a long-term practice of struggle against wind and sand, the farmers in the east of Henan Province intercrop shrubby ash with crops that made a distinctive model of agroforestry which has come to be called "shrubby ash-crop intercropping." In order to ascertain the biological and ecological properties, and to determine the suitable growing environment and develop the cultivation technology, especially in the intercropping system, a long-term study on shrubby ash was carried out in Ningling County of Henan Province. The main research results are included in this paper.

The Growth Pattern of Shrubby Ash

Twigs of shrubby ash are cut annually and branches are cut when they reach three years of age. The plant regenerates by resprouting for over 100 years if managed well. So it is important to study the growth pattern of shrubby ash for better understanding the resprouting ability at different growing stages, and guiding the production measures such as tending, regeneration, etc. According to the age, number, height and diameter of twigs, the life of the tree can be divided into three stages (Table 1). (1) *Young growth stage (1-10 years old)* - In the first three years (seedling stage), shrubby ash attains 50-60% of height growth of the adult stage, with main roots well developed. Twigs cannot be cut at this stage. From year 4 to year 10 (young plantation stage), the root system is well developed. Twigs can be cut, but not appropriate to produce ash rods at this stage. (2) *Adult stage (11-60 years old)* - Stems can be cultivated to obtain rods in this stage. It is the best stage for the shrubby ash tree to produce twigs and rods. (3) *Aged regeneration stage (over 60 years old)* - With the increase in age and cutting of twigs and rods every year, the growth slows down and the production of twigs and rods decreased. The root system degenerates.

Cultivation Technology of the Shrubby Ash Tree

Vegetative Propagation -

Shrubby ash tree can be easily propagated by cuttings and the survival rate is very high. (a) *Nursery preparation* - In general, fertile and well-drained sandy loam and loam are good soils for nurseries. Soil must be prepared carefully. After deep ploughing, base fertiliser (barn-yard manure or compost) should be added. After that, nursery beds size 1 x 10 m is made and ready for cutting. (b) *Shoot selection* - The cuttings can be from 1-2 years old saplings or twigs. The diameter of the shoots should range from 1-2 cm. The shoots can

Table 1. Growth of shrubby ash tree in different ages.

Age (yr)	2	5	10	20	30	45	55	71	100
Twig number	3.4	19	30	49	61	70	69	65	51
Twig height (m)	35.7	41.8	73.6	70.5	68.2	78.7	70.6	54.8	46.9
Diameter* (cm)	0.30	0.45	0.50	0.58	0.64	0.76	0.74	0.36	0.48

** Diameter at ground level.*

Table 2. Relative wind velocity in ash-crop intercropping system with different structures.

Number of planting rows	Density	Relative wind velocity (%)					
		1H	3H	5H	10H	15H	Mean
1	0.4	74	70	71	80	88	76.6
2	0.6	70	65	64	75	85	71.8
4	0.7	65	67	70	73	29	70.8

Table 3. Evaporation in ash-crop intercropping fields.

Items	Distance (leeward)				Open field
	10m	20m	40m	Average	
Evaporation (mm)	13.0	13.3	13.6	13.3	14.9
Relative evaporation (%)	86.8	90.8	94.7	90.8	100.0
Reduction (%)	13.2	9.2	5.3	9.2	/

then be cut into 20-30 cm long pieces with at least three buds. The cut should be oblique and not torn. It is suggested that the cuttings are planted soon and if it is not possible, the cuttings can be temporarily placed in rice field for short duration (a couple of days). If the cuttings are collected in early winter to be planted next spring, the cuttings can be stored in sandy soil. (c) *Season and methods* - The best season for cuttings is early March. Cuttings should be inserted into soil obliquely, keeping a 60^{o} angle. The inserting depth is about 25 cm with one bud in the air. Irrigation should be carried out after insertion.

Propagation by Seeds -

Seeds of ash are ripe in October and the bunches fruits do not fall down from the mother tree. The ripen fruits can be collected by sickle, and air dried. Before storage, seeds can be disseminated by wind or water. Sowing season is in mid-March and the seeds should be vernalised before sowing. Ash seeds are sown in rows. The normal rate of seeding is 3 kg per mu (1/15 ha). Seed purity is 95% and germination rate of 75%, 30,000 seedlings can be raised from one mu of nursery, and height of seedlings can reach 30-40 cm in one year. Seeding, watering, loosening of soil and weeding should be carried out in time.

Establishment Techniques of Shrubby Ash Plantation -

The shrubby ash plantation can be established by four methods: burying cuttings, cuttings, seedlings and root division. The cuttings should be from 2-3 years old robust saplings and the season for planting cuttings is early spring or winter, unless the earth is frostbound. The cuttings can be buried 6-9 cm deep into the soil when ploughing. Both winter and spring periods are suitable for inserting ash cuttings. First, select robust 1-year old twigs and cut them into 20-30 cm long cuttings, then insert three to five ash cuttings into soil that have been prepared with the shape ".·." or "::", with planting space of 60-100 cm. The best season for

Table 4. Comparison of soil wind erosion between intercropped and open fields.

Number of rows	Erosion depth at different positions in ash-crop intercropping fields					Erosion depth
	3H	5H	10H	15H	Means	
2	0.19	0.16	0.15	0.15	0.16	0.77
4	0.13	0.33	0.29	0.44	0.30	0.74

Table 5. Biomass of ash-crop intercropping systems (tons/ha).

Spacing of barriers	Ash	Wheat	Maize	Peanut	Total	
					Wheat/Maize	Wheat/Peanut
22 m	8.644	15.779	12.880	6.563	37.302	30.985
10 m	19.017	9.772	12.144	6.188	40.933	34.977
8 m	23.772	10.533	11.806	6.016	46.111	40.320
4 m	47.543	7.740	10.120	5.156	65.402	60.439

Table 6. Productivity of ash-crop intercropping system (ton/ha/yr).

Spacing of barriers	Ash	Wheat	Maize	Peanut	Total	
					Wheat/Maize	Wheat/Peanut
22 m	2.093	15.779	12.880	6.563	30.751	24.434
10 m	4.694	9.772	12.144	6.188	26.609	20.653
8 m	6.120	10.533	11.806	6.016	28.459	22.669
4 m	12.245	7.740	10.120	5.156	30.105	25.141

outplanting of seedlings is spring. Seedlings should be carefully lifted from the nursery and transported to the planting site. Root systems and top buds of seedlings should be protected during the lifting and transporting. In winter, some stumps with roots can be divided from the plantation in which the density is too high. The divided stumps can be stored in winter and replanted next spring.

Management of Shrubby Ash Plantation -

In the early period of growth, for protecting the root system, soil cultivation should be carried out in the winter season. The root system will develop well during first three years. The season for cutting twigs in the 4th year is autumn when the leaves have fallen. The height of stumps is 3-5 cm and it should be covered by soil after twig harvest. Fertiliser application is also needed for high yield in ash plantations. Both chemical fertiliser and farm manure can be used. In addition, superfluous branches should be removed in the summer, and special attention should be paid to control harmful pests. The adult growth stage is an important period for rod and twig production (Table 1).

The root system of ash trees in the adult growth period is very robust. Because the ash tree is usually planted in farmland, the root system will over develop if there is no appropriate control. This will harm agricultural crops and negatively affect the production of twigs and rods. Therefore, the root system must be controlled by deep ploughing of the soil between shrubby ash tree rows (1-2 m apart from the planting rows) in the spring. In order to obtain high quality rods without nodes, superfluous branches should be pruned in the summer season.

The main kinds of pests are longicorn and shell-insect. Poisonous bamboo arrow and cotton dipped in 80% DDVP or 40% Rogor emulsion can be inserted in the holes to control longicorn. In addition, cutting wounds of ash must be sterilised with 0.5-1 degree lime-sulphur mixture to prevent harmful pathogenic bacteria from entering after twigs or rods are cut. After the robust growth stage, the ash tree enters slow growth period. The ability of sprouting, production of twigs and rods decline. The major management activities include irriga-

Table 7. **Comparison of circulation rate (CR) of nutrient elements between intercropping and monoculture systems (kg/ha/yr).**

	Items	N	P	K	Ca	Mg	Mn	Total
Ash-crop inter-cropping system	Retain	247.23	40.83	152.05	355.07	92.37	1.06	888.60
	Absorb	273.90	42.38	157.81	157.81	97.70	1.23	948.47
	Return	26.68	1.55	5.76	20.38	5.33	0.17	59.87
	CR	0.0974	0.0367	0.0365	0.0543	0.0546	0.1346	0.0631
Mono-culture system	Retain	236.77	38.05	147.79	349.83	90.69	1.02	864.16
	Absorb	259.23	39.13	151.91	365.93	94.77	1.17	912.15
	Return	22.46	1.08	4.13	16.93	4.08	0.14	47.99
	CR	0.0866	0.0276	0.0272	0.0440	0.0431	0.124	0.0526

tion, fertilisation, etc. to keep the plants healthy.

Cultivation of Rods (Long Stems) -

Rods obtained can be used to make small furniture, handles and sporting goods. Rods protect the tree in intercropping system and rod cultivation is an important way to manage shrubby ash. Farmers collect rods when the ash tree is 10 years old, by then the root system will have developed completely. But in good site conditions, rods can be cultivated ahead of this schedule.

In the stage of 10-20 years, the growth of ash tree twigs decreased by 30% and the number decreased by 60% if one rod is kept per stump. But if two rods are kept, there was a 50% reduction in height growth and 60% in twig number. Keeping three rods, there was a 63% reduction of height growth and 75% in twig number. Concerning the length of time for cultivation of rods, four to five years will be needed for one rotation of rod cultivation if three rods are kept per stump. Only three years needed if one or two rods per stump are kept. The old plants are unsuitable to cultivate rods. When cultivating rods, robust and straight twigs must be selected and kept well-distributed on the stump. To increase the quality of rods, superfluous buds should be removed. The top bud should also be removed when the rods reach 3 m in length, thus promoting a greater diameter. The standard period for rod harvest is in autumn after leaf fall.

Ecological and Economic Benefits of Shrubby Ash-Crop Intercropping

Ash-crop intercropping farming systems, as in other agro-forestry systems, such as *Paulownia*-crop intercropping and shelter belt systems in farmland, can improve the microclimate of the farmland and crop growth. A wind break is formed by ash rods (upper layer) and twigs (lower layer). The rate of wind break is 0.3-0.7 and protection effect against wind is very obvious. In the range from the ash tree to 15H (H is the height of tree), wind velocity is reduced by 20-30% (Table 2).

Temperature - As the wind velocity changes, the air exchanges in both horizonal and vertical directions weaken. So, the air temperature in the field also changes, but the pattern is complicated. The air temperature in the intercropping system, compared with the open field, increased by 0.5-0.8°C in winter and early spring, and decreased by 0.5°C in summer.

Evaporation - Average evaporation reduction of 10% was found in the range from the ash tree belt to 15H (leeward) (Table 3).

Soil moisture - Ash barriers conserve soil water and increase soil moisture by the reduction of wind velocity and evaporation. Under inter-cropping system, there was a 6.7% increase of water content, 11.3% increase of available water content, and a 5% increase of soil moisture in the upper layer of soil (0-60 cm) during the growing season of wheat. Ash barriers can also conserve snow drifting and increase soil water in winter.

Table 8. **Comparison of soil microbe numbers in intercropping systems and open field.**

Sites	Soil microbes	Number of microbes in 1 g of dry soil
Intercropping system	Fungus	2.40×10^5
	Germ	1.03×10^9
	Actinomyces	2.98×10^6
Open field	Fungus	4.26×10^5
	Germ	1.38×10^9
	Actinomyces	5.41×10^6

Air humidity - In the range of 15H from the ash tree rows, there is a 20% increase of relative humidity (absolute humidity increases of 5 mb) in daytime compared with the open field. In the prevailing season of hot winds, the increase of relative humidity can reach up to 20%.

Radiation - Gross radiation is reduced in ash-crop intercropping fields depending on the spatial direction of shrubby ash barriers. Ash barriers in the south-north direction with spacings of 30 m could reduce gross radiation by 5%. However, a 6.1% reduction was found in an intercropping field with ash barriers in the east-west direction. But scattered radiation increased in intercropping fields because of the reflection of ash barriers. Scattered radiation increased by 3.7% and net radiation by 4.2%

Reduction of wind erosion - In spring of 1986 soil erosion decreased by 9.5% in shrubby ash-crop intercropping fields compared with the open fields (see Table 4).

Increase of Productivity and Circulation Rates of Energy and Materials -

Shrubby ash-crop intercropping ecosystems can make full use of sunshine and other natural resources. It can increase the biomass production of the land. The biomass increase (Tables 5 and 6) showed that the biomass accumulation of ash-crop intercropping systems reached 30.9851-65.4078 tons/ha with an annual productivity of 20.6529-30.7511 tons/ha/yr. Calculated according to a commonly used photosynthetic formula (4176 Kcal energy needed for synthesis of 1 kg biomass) and the total annual radiation of 119 Kcal/cm^2, the energy use efficiency of the ecosystem is up to 0.7-1.1%. The circulation rate of nutrients in ash-crop intercropping system is higher than that in monoculture systems (Table 7).

Biological Functions -

The ecosystem provides a good habitat for small animals, insects and microbes. According to observations, over ten frogs were found in the 20 m long ash barrier and there were 20% more arthropods present in surface soil than in open fields. The natural insect enemies of plant pests increased by 17% in total population in the intercropping systems compared to open fields (Table 8).

Crop Yield in Ash-Crop Intercropping System-

After many years of observation of intercropping systems, it has been shown that intercropped wheat yields increase by 7-10%, soybeans by 5% and peanuts by 4.7% compared with the monoculture of the same crops.

Purlin Plantation with Intercropping and its Economic Benefits

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ABSTRACT

This paper reports the results of experiments conducted in the North China Plain on purlin plantation with intercrops. The fast-growing plantation of Populus x euramericana cv. 'Sacrou 79' can reach the state standard for purlin timber within four years. With planting spacing of 3 x 6 m and intensive cultivation during the first three years, the timber output reached 66.144 m^3/ha, of which 63.6% was purlin timber, 25.90% small logs and 25.9% fuelwood. The total profit after principal felling, reached 28,830 Chinese Yuan (RMB) per ha (8,760 Chinese Yuan (RMB) from intercrops, and 20,070 Chinese Yuan (RMB) from timber), more than 7.5 times of the total investment.

Introduction

North China Plain, with a high population density and limited land resources, is well developed in agriculture, but short in forest products. It is impossible to establish large scale pure plantation forests to solve this problem because it would cause a decrease in the output of food and other agricultural products. Agroforestry should be an acceptable method to solve this problem, i.e., to combine forest trees and agricultural crops together and get both agricultural products and forestry products from the same piece of land. For this reason, with cooperation from local farmers, an experimental agroforestry model for both the purlin timber production and agricultural crops was established in Wangdu County of Hebei Province in 1983. This paper presents results from the first rotation of the experimental plantation.

Site Description and Research Methods

The experimental site was in North China Plain where the general topography is flat, with a slight slope from southwest to northeast with warm temperate, semi-humid climate. The area is dry and windy in spring; with high temperatures, and plenty of rainfall in summer; clear and sunny skies in autumn; dry and cold in winter, with an annual average temperature of 11.2°C, rainfall of 582.4 mm, evaporation of 1846.4 mm and frost-free period of 172 days. The site has alluvial loose, sandy soil, with pedogensis, poor fertility, well-ventilated, and with suitable groundwater elevation, all the conditions suitable for cultivation, except for its lack of organic matter and other elements such as nitrogen and phosphorus.

Populus x euramericana cv. 'Sacrou 79' was selected to establish experimental plantation on 24-25 March 1983, covering 300 mu (20 ha) of land, 145 mu was planted with trees for purlin (100 mu of 3 x 6 m spacing, 45 mu of 4 x 6 m spacing), and 155 mu with trees of big diameter for timber (6 x 6 m spacing) and trees for other purposes. Planting holes size 1 x 1 x 1 m were dug two to three days before planting, and 100 kg barnyard manure and 1 kg calcium superphosphate was applied for each planting hole. One-year old seedlings with a height of 3-4 m and DBH of 1.5-3.0 cm were used. The seedlings were soaked in water for one or two days before planting. From 1983 to 1985, intercropping was conducted which showed normal growth in the first two years; but notably declined in the third year. In the fourth year, the intercropping had to be stopped because most crowns of the trees were closed. Eighteen mixed sample plots were selected, each consisting of 30-60 trees, for experimentation. Various data were collected for

Table 1. Growth data of the experimental plantation.

Items	Spacing m x m	Basic data	1983	1984	1985	1986
Tree height (m)	4 x 6	3.86	4.84	7.64	11.48	13.94
	3 x 6	3.65	4.47	7.12	11.51	14.26
Diameter B.H. (cm)	4 x 6	2.00	3.87	8.75	13.73	17.33
	3 x 6	1.95	3.59	8.21	13.37	16.61
Annual growth/H	4 x 6		0.89	2.89	3.84	2.46
	3 x 6		0.82	2.65	4.39	2.75
Annual growth/D	4 x 6		1.87	4.88	4.98	3.60
	3 x 6		1.64	4.62	5.16	3.24
Volume (m^3/tree)	4 x 6	0.0007	0.0031	0.0021	0.0745	0.1301
	3 x 6	0.0006	0.0025	0.0184	0.0710	0.1218
Volume (m^3/ha)	4 x 6	0.2910	1.2900	9.1995	31.0110	54.1545
	3 x 6	0.3330	1.3875	10.2120	39.4050	67.5990

Table 2. Timber assortment distribution after felling.

Spacing m x m	Volume m^3/ha	Purlin timber		Small logs		Fuelwood	
		m^3/ha	%	m^3/ha	%	m^3/ha	%
4 x 6	50.8125	36.4830	71.8	9.6030	18.9	4.7625	9.3
3 x 6	66.1440	42.0675	63.6	17.1315	25.9	6.9450	10.5

each tree.

Performance of the Experimental Plantation

The growth data of the experimental plantation is listed in Table 1. The data indicates that the trees grew fast in second year, after a restoration period in the first year. The growth peak appeared in the third year with a slight decline in the fourth year, because the crowns were mostly closed at this time.

The data collected in 1987 is presented in Table 2 when purlin plantation was cut down. The timber volume of a unit area with 4 x 6 m spacing was 15.3315 m^3/ha less than that of 3 x 6 m spacing. Although the proportion of purlin timber in 4 x 6 m spacing was higher than in 3 x 6 m, the actual purlin timber yield from the former was 5.5845 m^3/ha less than the latter. The output of fuelwood (top log) between the two spacings was similar, but the output of small logs between the two spacings was different, reaching up to 7.5785 m/ha. The output of purlin timber from the plantations with different spacings both surpassed 60%, fulfilling the state standard (Table 2).

Economic Benefits

In the first and second years of intercropping, the agricultural yield was high with considerable profit after covering the cost of plantation management and intercropping. But in the third year the crowns of the trees begin to close and both the output and quality of crops greatly declined, with a deficit balance. In the fourth year there was no intercropping but high profit was obtained after the felling of trees (Table 3). The average annual net profit of the plantations were 6,251.33 and 5,257.84 CNY/ha respectively, corresponding to the different spacings of 3 x 6 and 4 x 6 m. These figures are 1.5-2.1 times higher than pure crop culture under the same conditions.

Discussion

It has been shown in this experiment that three

Table 3-1. Balance sheet of purlin timber plantation management. Spacing: 3 x 6 m (CNY/ha).

Year	Items	Costs	Revenue	Profit
1st (1983)	Forestry	679.35		
	Intercropping	855.00	3,750.00	
	Total	1,534.35	3,750.00	2,125.65
2nd (1984)	Forestry	364.50		
	Intercropping	792.45	4,289.85	
	Total	1,156.95	4,289.85	3,132.90
3rd (1985)	Forestry	282.15		
	Intercropping	633.15	720.00	
	Total	915.30	720.00	-195.30
4th (1986)	Forestry	219.45	20,071.50	
	Intercropping			
	Total	219.45	20,071.50	19,852.05
Total		3,826.05	28,831,35	25,005,30

Table 3-2. Balance sheet of purlin timber plantation management. Spacing: 4 x 6 m (CNY/ha).

Year	Items	Costs	Revenue	Profits
1st (1983)	Forestry	514.05		
	Intercropping	855.00	3,750.00	
	Total	1,369.05	3,750.00	2,380.95
2nd (1984)	Forestry	302.25		
	Intercropping	792.45	4,290.00	
	Total	1,094.70	4,290.00	3,195.30
3rd (1985)	Forestry	230.85		
	Intercropping	633.15	720.00	
	Total	864.00	720.00	-144.00
4th (1986)	Forestry	193.05	15,792.15	
	Intercropping			
	Total	193.05	15,792.15	15,599.10
Total		3,520.80	24,552.15	21,031.35

years' intercropping in the purlin timber plantation with 3 x 6 m spacing and four years' rotation is possible and the purlin timber planation management did not reduce the gross output of local agriculture. 3 x 6 m spacings were found to be perfect for this area when the abovementioned superior clone was planted in a suitable site with intercropping. The cost of 3 x 6 m spacings was about 3,825 CNY/ha with the total profit after principal felling was 28,830 CNY/ha, 7.5 times higher than the initial investment. It is estimated that if an average village in North China Plains could use 400 mu (26.67 ha) of farmland to establish 100 mu purlin timber plantation each year with four years' rotation, it would get up to 440 m of timber each year, with a value of 166,701.40 CNY of steady net profit. This revenue is greatly needed for small villages in North China.

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Intercropping with *Populus Tomentosa* and its Beneficial Effects

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ABSTRACT

Populus tomentosa-crop intercropping with emphasis on forestry is a newly developed farming pattern. The results of the experiments showed that intercropping in young forest stands effectively promoted the growth of Populus tomentosa and the intercropped crops also gave good harvests because of the young trees influencing the microclimatic conditions. Based on the analysis of total benefits of tree growth and crop yield, the best period of intercropping was the first three years. The suitable tree planting spacings for intercropping were 4 x 6 or 4 x 8 m. Suitable crops were those with shallow roots like wheat and cotton.

Introduction

Western Shandong Plain is situated in the semi-moist monsoon region of warm temperate zone, where the average annual temperature is about 13°C with maximum and minimum of around 41°C to -20°C respectively, annual frostfree period about 200-210 days and total annual rainfall 580-600 mm. The temperature rises quickly in spring but with slight rainfall at that time. The frequent dry-hot wind is often injurious to crops.

Western Shandong Plain was formed by the deposition of the Yellow River and forest land is mainly sandy wasteland. Major soils are sandy Chao soil (SCS), loamy Chao soil (LCS), and sandy Chao soil with loamy layer (SCSLL). The fertility of these soils is very poor. The income from agriculture is very low because of poor soil fertility, drought, waterlogging and sand. Rural population is about 17.48 million with per capita land of 0.143 ha. Of these, 0.134 ha are farmland and 0.09 ha are woodland. Development of forest tree/crop intercropping systems is a effective way for reducing forestry management costs and fully utilising natural resources.

Materials and Methods

The experimental plots were located at Wanshen and Pushang villages of Guanxian County in

Table 1. Growth pattern of *Populus tomentosa* in different management systems*.

Management systems	Apr	May	Jun	Jul	Aug	Sep	EDV**	ATI***
Intercropped	0.59	0.76	0.90	0.83	0.46	0.00	0.44	3.54
Pure/Fertilised	0.16	1.50	0.80	0.11	0.13	0.32	1.18	3.02
Pure/Unfertilised	0.01	0.17	1.18	0.79	0.41	0.00	0.77	2.56

* Three-year old stands with loamy Chao soil.
** EDV: Extreme Difference Value.
*** ATI: Annual Total Increment.

Table 2. Annual increments of *Populus tomentosa* under different management systems.

Soil types	Growth items	Management systems	1983	1984	1985	1986	1987	Mean
Loamy Chao Soil	Height (m)	A.Intercropped	5.13	8.34	9.69	12.36	13.51	9.81
		B.Fertilised	4.93	7.39	9.67	11.87	12.75	9.42
		(A/B)*100%	104	106	101	104	106	104.2
		C.Unfertilised	4.60	7.34	8.39	10.56	11.17	8.41
		(A/C)*100%	111	114	115	117	121	115.6
	DBH (cm)	A:Intercropped	5.30	9.35	13.70	16.55	18.90	12.76
		B.Fertilised	5.98	9.01	12.52	15.39	16.33	11.85
		(A/B)*100%	87	104	109	107	116	104.6
		C.Unfertilised	5.01	8.111	0.53	13.01	13.75	10.08
		(A/C)*100%	106	115	130	127	137	123.0
Sandy Chao Soil With Loamy Layer	Height (m)	A.Intercropped	5.80	8.50	9.60	11.11	12.70	9.54
		B.Fertilised	5.35	7.20	8.10	9.30	10.30	8.05
		(A/B)*100%	108	118	119	119	123	117.4
		C.Unfertilised	5.20	6.40	7.50	8.70	9.50	7.46
		(A/C)*100%	112	133	128	127	134	126.6
	DBH (cm)	A.Intercropped	4.90	5.08	8.33	10.03	12.40	8.15
		B.Fertilised	3.00	3.10	5.23	8.20	10.80	6.07
		(A/B)*100%	163	164	159	122	115	144.6
		C.Unfertilised	2.90	3.02	4.30	7.90	10.40	5.70
		(A/C)*100%	169	168	194	127	119	155.4

Notes:
1. Intercropped crop was wheat and intercropping was only taken in the first three years.
2. The dosage of fertilisers were urea 0.48 kg/tree/year, $CaH_4(PO_4)_2H_2O$ 0.45 kg/tree/year, and K_2SO_4 0.28 kg/tree/year for loamy Chao soil and 0.46,0.075, and 0.075 kg/tree/year respectively for sandy loamy Chao soil with loamy layer.

the Western Shandong Plain. The trial plantations with species of *Populus tomentosa* were established with planting spacings of 4 x 5, 5 x 6, 6 x 8 and 5 x 10 m from 1983-1985. The soil types of the trial site were sandy Chao soil, sandy Chao soil with loamy layer and loamy Chao soil. The major intercropped crop is wheat.

The solar intensity was determined using an illumination meter in the middle of each month from April to September, measurements were taken every two hours from sunrise to sunset. Soil moisture and nutrients were determined each month. The distances from sampling places to trees were 0.5, 1, 1.5, 2, 3 and 3.5 m. Soil moisture samples were obtained from soil depths of 0-20, 20-40, 40-60 and 50-80 cm at each sampling place. A soil nutrient sample was obtained from the soil depth range of 0-60 cm. The diameter at breast height, tree height and growth and distribution of root system of the trees were surveyed at an interval of one month. The crop yields were investigated at the end of each year.

Results And Discussion

The Effects of Intercropping on Growth of the Trees -

To evaluate the effects of intercropping on the growth of the trees, the growth data of intercropped stands was compared with the pure stands cultivated under similar conditions.

The growth pattern data of the intercropped stand of *Populus tomentosa* with comparison to that of pure stands (fertilised and unfertilised) are

Table 3. Outputs of different *Populus tomentosa* plantations with different planting spacings.

Soil	Spacing	Items	Year 1	Year 2	Year 3	Year 4	Year 5
Loamy	4 x 6 m	Volume (m/ha)	5.10	20.85	33.60	54.30	87.30
Chao		Crop yield (kg/ha)	4875	4875	3225	1875	/
Soil	6 x 8 m	Volume (m/ha)	3.00	12.00	24.00	35.55	55.55
		Crop yield (Kg/ha)	5025	4725	3150	1950	/
Sandy	6 x 8 m	Volume (m/ha)	1.35	2.70	11.25	14.85	29.10
Chao		Crop yield (kg/ha)	3000	1875	1500	1125	/
Soil	5 x 10m	Volume (m/ha)	1.20	2.40	9.60	11.40	24.60
		Crop yield (Kg/ha)	3150	2100	1650	975	/

Table 4. Economic analysis of intercropping of wheat under *Populus tomentosa* plantations from years 1-5.

Spacings & soil types	Items	Year 1	Year 2	Year 3	Year 4	Year 5
Loamy Chao soil	Yield (kg/ha)	4875	4875	3225	1875	750
4 x 6 m	Gr. income (CNY/ha)	3120	3120	2064	1215	240
	Cost (CNY/ha)	1500	1500	1500	1500	1500
	Profit (CNY/ha)	1620	1620	264	-300	-1260
Sandy Chao soil with	Yield (kg/ha)	3375	2850	1725	1350	750
loamy layer	Gr. income (CNY/ha)	2160	1335	1104	864	225
6 x 8 m	Cost (CNY/ha)	750	750	750	750	750
	Profit (CNY/ha)	1410	594	354	114	-525
Sandy Chao soil	Yield (kg/ha)	3150	2100	1650	975	450
5 x 10 m	Gr. income (CNY/ha)	2016	1334	1056	625	144
	Cost (CNY/ha)	750	750	750	750	750
	Profit (CNY/ha)	1266	594	306	-126	-606

shown in Table 1. The intercropped stand had the highest DBH increment and the DBH growth peak appeared from May to July, while the highest values for the pure stands lasted only two months each (May to June in fertilised stands and June to July in unfertilised stands). In loamy Chao soil, the tree height growth of intercropped stand was 6% higher than that of the fertilised pure stand, and 21% higher than that of the unfertilised pure stand. DBH increment of the intercropped stand was 16% higher than that of the fertilised pure stand and 37% higher than that of the unfertilised pure stand. Similar differences in sandy Chao soil can also been seen in Table 2.

Selection of Planting Spacings of *Populus tomentosa* in Intercropping Stand -

The main goal of intercropping crops in *populus* stand in the area is to improve tree growth through intensive cultivation of intercropped crops. At same time, integrated economic benefits from both the timber production and crop output are also considered. In order to reach the goal of both tree growth promotion and greatest profits from the plantation, planting spacings of trees should be properly selected. The data listed in Table 3 shows the outputs of different plantations with tree planting spacings of 4 x 6, 6 x 8 and 5 x 10 m. The planting spacings of 4 x 6 - 5 x 10 m affected very little crop yield and timber volume accumulation was affected considerably (Table 3). In general, the narrower the spacings were, the higher the stand volume was. The suitable spacings of trees in the intercropped stands in which forestry takes the main part are 4 x 6 and 6 x 8 m. These spacings hardly affected crop yield, but increased stand timber volume.

Period of Intercropping -

The proper period for intercropping was deter-

Table 5. Fast-growing period of *Populus tomentosa* in different site conditions. (Age from beginning to end).

Site conditions	DBH Year-Year	Height Year-Year	Volume Year-Year
Sandy Chao soil	2 - 5	1 - 4	3 - 5
Loamy Chao soil	2 - 9	1 - 10	4 - 6
Sandy Chao soil with loamy layer	2 - 8	1 - 8	4 - 12

mined by using economic factors. Table 4 lists economic benefit data of different intercropping plantations from year 1 to year 5. The proper period of intercropping different site conditions and planting spacings were in first three years. Economic benefits were low in year 4 and year 5. It is shown in Table 5 that the fast-growing period of tree volume begins the fourth year after planting. At that time, trees need large amount of water, energy and nutrients for their growth. The competition between trees and crops for water and other natural resources becomes obvious. So it is not suitable to continue intercropping at four years and thereafter.

Conclusion

i) Combination of forest and agriculture, so called agroforestry, is an effective way of forestry development in Western Shandong Plain.

ii) Under the *Populus tomentosa*/crop intercropping farming system, growth conditions of the trees are improved because of the intensive management of agriculture crops, especially in the poor sites.

iii) The suitable planting spacings of trees in *Populus tomentosa*/crop intercropping systems are 4 x 6 or 6 x 8 m according to the site conditions.

iv) The intercropping of crops in *Populus tomentosa* forest plantations can only be taken in the first three or four years.

v) The root systems of *Populus tomentosa* mainly distribute in the depth range of 30-40 cm, so the intercropped crops should be those with short root systems such as wheat and cotton.

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Utilisation of Poplar Leaf as Fodder

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ABSTRACT

The poplar cultivation system along with other agricultural practices is of great economic value in highly populated areas where farmland is precious and fodder is scarce. Besides extracting boles from trees the poplar leaves are used as valuable fodder, the quality of which is compared with other fodder materials.

Introduction

Since the 1970s, the fast-growing and high-yielding poplar plantations have rapidly developed in plain farmland areas in China, followed by intercropping system. Traditionally, boles are extracted from trees and other massive biomass is ignored. It is a waste in highly populated areas where the farmland is precious and fodder is lacking. In 1984, a poplar cultivation system combining agriculture, forestry and animal husbandry was designed, and the experiment was carried out in Linyi Prefecture, Shandong Province.

Specialised households contracted 5 ha of young poplar. Two to three years after planting, intercropping was conducted. After canopy closure, forest management was combined with animal husbandry and the poplar leaves were used as fodder. In addition to the benefit of intercropping, the system has the following advantages: 1) Mass of poplar leaves are grazed by animals in plantation areas; 2) Animal manure can make its way back to the field; 3) The combination of the long cycle of forest production (rotation period of five to eight years) and the short cycle of animal husbandry improves rural economic development; 4) Extra labour in rural areas can be employed.

Methods

The leaves collected from *Populus deltoides* I-69/55, *P. euramericana* I-72/58 and *P. euramericana* I-214 were used as animal feed. The leaf yield was estimated by cutting five sample trees for each spacing, from which fresh leaves were collected and weighed. The amino acid in foliage was determined by using the Water Amino Analysis System, and leaf crude protein was determined by K.J. method. Crude fiber was analysed by the acid-alkali method. The residue method was adopted to determine the ether extract. The calcium content was determined by using the EDTA in volumetric method. The ash content was determined by method of incineration. The calorimetric analysis was used for determination of the phosphorous content.

Results

Leaf Collection and its Chemical Composition-
The leaves were collected by pruning and cutting. Trunks were pruned of 3-year old trees and up to 5-8 m and 1-3 kg of fresh leaves were harvested from each tree every year and 555-1,666 kg of leaves can be harvested per ha (under the spacing of 3 x 6 m). A greater amount (11,250-15,000 kg/ha) can be collected if poplar plantations are cut in the growing season, i.e., September to October. Leaves which fall in autumn or are blown down by strong winds can also be stored and used.

1) *Processing and storage:* To store leaves for a long period and prevent them from going bad, the fresh leaves, after they are dried, can be ground into leaf flour which is dark green and smells sweet. Mixed with other concentrated feed, it will be palatable for rabbits, pigs and

Table 1. A comparison of leaf chemical composition of three poplar clones and other fodder (% in dry matter).

Source	Dry matter	Crude protein	Crude fiber	Ether extr.	Ash	Ca	P	NFE
Populus I-69/55 CIJ.	93.82	12.79	19.60	2.31	16.47	3.95	0.09	48.65
Populus I-72/58 CIJ.	93.28	13.28	17.61	2.69	16.18	3.75	0.09	50.22
Populus I-214 CIJ.	92.86	13.56	18.91	2.47	15.05	3.45	0.12	50.01
Populus I-69 CIN.	93.07	10.53	17.52	3.35	13.58	2.96	0.07	55.01
Oat residue	95.20	6.09	35.50	1.89	10.92	0.13	0.02	45.58
Hay	90.90	6.93	23.10	1.76	19.80	0.31	0.29	48.29
Sweet potato residue	88.00	9.20	32.38	3.06	11.02	1.55	0.11	44.32
Alfalfa ray	88.40	17.53	28.73	2.60	9.04	1.10	0.22	42.08
Leaf of black locust	88.00	22.61	17.61	2.61	7.95		0.15	48.98
Maize	85.50	8.25	1.81	5.42	1.69	0.10	0.30	82.82

NEF: nitrogen free extract.
CIJ: collected in July.
CIN: collected in November.

chickens. Silaged poplar leaves are soft, juicy and palatable with a sour and sweet smell and can be stored for a long period of time.

2) *Yield of poplar leaves:* Our analysis of the leaf area per tree, dbh, height and volume (d^2h) of young *P. deltoides* lux I-69/55 showed that there is a linear correlation between leaf area and the other three factors. The correlation coefficients are 0.870, 0.874 and 0.905 respectively and reach a highly significant level.

Five-year old plantation of *P. deltoides* lux I-69/55 with spacings of 3 x 3, 3 x 4 and 3 x 5 m produced 9,790-10,600 kg/ha fresh leaves per year, corresponding to 3,626-4,038 kg/ha of oven-dry weight with leaf area index was 3.5-4.0.

Irrigation affects the amount of poplar leaves. The yield of fresh leaves of 2-year old irrigated (374.2 mm) *P. deltoides* lux I-69/55 in the growing season was 8,605 kg/ha; compared to controls (no irrigation) was 3,499 kg/ha. The highest yield of fresh leaves with irrigation was 17,589 kg/ha, the leaf area index was 5.9; the yield of the fresh leaves and the leaf area index of the controls were 12,700 kg/ha and 3.8.

To find the nutrient contents and chemical composition, the leaves of the widely planted *P. deltoides* lux I-69/55, *P. euramericana* I-72/58, *P. euramericana* I-214 in Linyi, Shandong were analysed. Table 1 shows that the content of crude protein of the leaves of the three poplar clones in July was 12.97-13.56%, which was lower than that of alfalfa hay and leaf of black locust and higher than that of oat residue, hay, sweet potato residue and maize. The crude protein in the leaves of *P. deltoides* lux I-69/55 in November was 10.53%, i.e., 19% reduction compared with that in July. However, it was still higher than that of potato residue and the other three kinds of fodder.

The poplar's characteristic of high need for nitrogen is reflected by the high nitrogen content of poplar leaf. Usually the intensively cultivated poplars are supplied with nitrogenous fertiliser. When there is enough nitrogen, the nitrogen content in the leaf of *P. deltoides* lux I-69/55 was more than 2%, its crude protein was equal to its nitrogen content 6.25 times. The nitrogen content of the three poplar clones in this experiment were all higher than 2%. The ether extract contents of the three poplar clones were between 2.31-3.35%, which was almost the same as those of alfalfa hay and leaf of black locust, and higher than those of oat residue and hay. The nitrogen free extract contents of the poplar leaves were similar to those of the five types of fodder except for maize. The Ca contents of the poplar leaves were higher than those of the other six types of fodder.

The amino acid compositions of the three poplar leaves were also distinctly higher in July, 4.16-4.81% (Table 2) and composition changed with seasons. In comparison with the forages such as Chinese Milkvetch (*Astragalus sinicus* L.), fresh leaves, residue and grain of maize, poplar leaf had higher content of seven amino acids, lysine content in July and November was higher. The total soluble

Table 2. Amino acid comparison of poplar leaf (g/100 g)

Amino acid	1	2	3	4
Aspartic acid	0.507	0.399	0.506	0.586
Threonine	0.212	0.138	0.272	0.315
Serine	0.229	0.169	0.244	0.270
Glutamic acid	0.332	0.231	0.347	0.284
Glycine	0.281	0.169	0.311	0.276
Alanine	0.510	0.323	0.434	0.453
Valine	0.315	0.200	0.343	0.329
Methionine	0.102	0.045	0.0305	trace
Isoleucine	0.272	0.161	0.305	0.281
Luecine	0.416	0.284	0.541	0.514
Tyrosine	0.187	0.169	0.249	0.245
Phenylalanine	0.246	0.169	0.269	0.245
Lysine	0.314	0.269	0.429	0.476
Arginine	0.246	0.138	0.365	0.539
Total	4.169	2.864	4.646	4.813

1 = *Populus* I-69/55 collected in July.
2 = *Populus* I-69/55 collected in November.
3 = *Populus* I-72/58 collected in July.
4 = *Populus* I-213 collected in July.

sugar content in the foliage of the three poplar clones ranged from 10,529.74 mg/100 g in July and total soluble sugar content in the leaf of *P. deltoides* lux I-69/55 reached 6,952.83 mg/100 g in November.

Feeding Test -

Twenty long-haired West German rabbits of same age and weight were chosen for the feeding test. They were divided into two groups - the test group and the control group. Before the test, hair was cut and the vaccine was injected. The test began on 1 August and completed in 1 November; within these 90 days, they were weighed three times. (The weighing was done in the morning on an empty stomach). At the end of the test, the hair was cut and weighed. Each rabbit in the test group was fed with 125-250 g dry poplar leaf flour every day; those in the control group was fed with 600 g fresh grass. The compound fodder added to each group was the same - 50 g. Leaf flour accounted for 71-75% of the total fodder for test group. Table 3 shows that wool production of long-haired rabbits was almost the same as that of green grass. The statistical t-test was not significant.

Table 3. Effect of poplar leaf flour on the weight growth and the wool production of long-haired rabbits

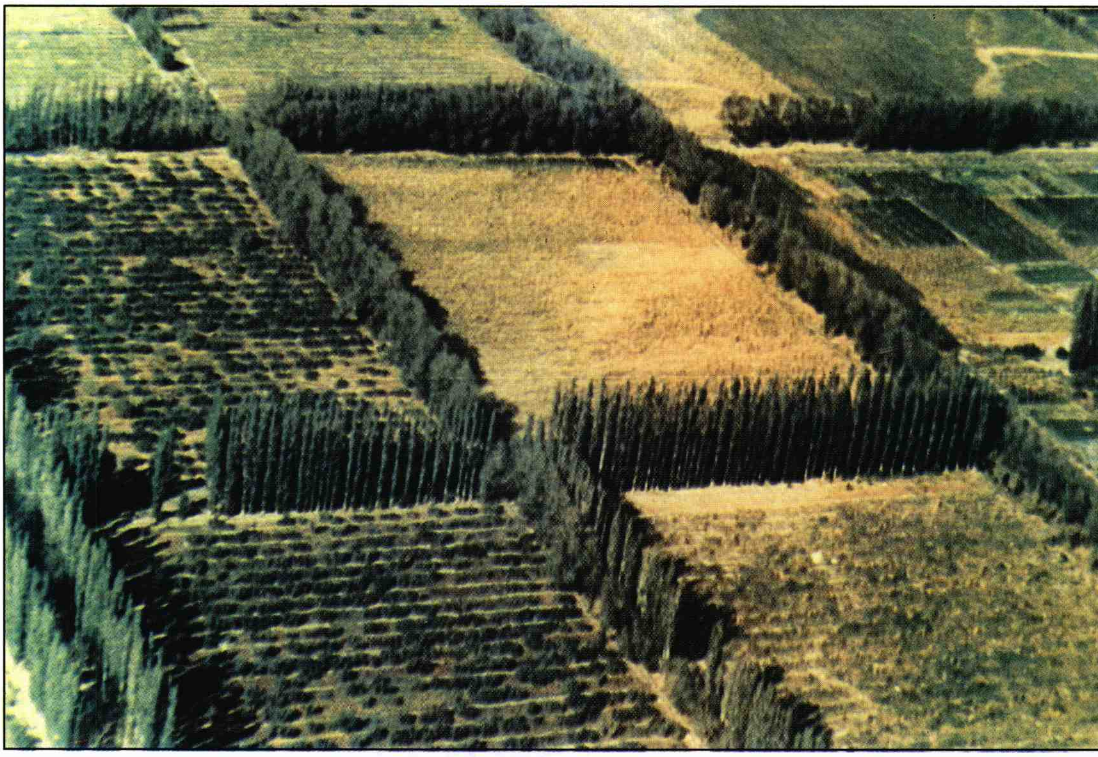
	Treatments	
Measurements	Test group (g)	Control group (g)
Average initial weight	2158 ± 73*	2186 ± 58
Average weight in intermediate stage	2718 ± 71	2715 ± 58
Average weight the end	3216 ± 56	3199 ± 52
Average wool production	167 ± 6	159 ± 6

* *Standard division.*

Concluding Remarks

In plain farmland areas, the poplar cultivation system is combined with agriculture, forestry and animal husbandry, and carried out by utilising poplar leaves as fodder and returning excrement to plantations. The utilisation of forest products should not be confined to boles, but extended to the entire biomass. If 3,333 ha are cut each year, each ha has 7,500 kg leaves; then, 25 million kg fresh leaves can be utilised as fodder. Utilisation of poplar leaves as fodder is worth popularising. The poplar cultivation system combining agriculture, forestry and animal husbandry should be extended on the basis as the intercropping system which is widely implemented in China. It is the kind of agroforestry which fits the characteristics of rural areas in China and can bring remarkable economic benefits.

III. AGROFORESTRY SYSTEMS IN ARID AND SEMIARID ZONE



"Three Norths" Protective Forest System

Protective Forest System in Grassland

"Three Norths" Forest Protection System and its Benefits

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ABSTRACT

In order to control sandstorm damage, minimise soil erosion, improve ecological conditions and promote overall development of agriculture, forestry and animal husbandry, the large scale shelter belt system in northwest, north and northeast (Three Norths) parts of China were established in 1978. Total forest planting areas were 35.08 million ha, of which 62% will be accomplished by the year 2000. To-date, many benefits in ecological, social and economic aspects have been achieved.

Introduction

In order to improve the natural environment and social conditions of people in northern China and speed up comprehensive development of agriculture, forestry and animal husbandry, the Chinese government decided in 1987 to build a protection forest system in the region of northwest, north, and northeast China which were seriously affected by sandstorm and soil erosion. This came to be known as the "Three Norths" protection forest system for short and it was listed as one of the key projects in the country's national economic construction.

The project is guided by the theory of ecological economics, and carried out according to the principles of economics as well as social benefits for people. According to planning the overall construction range lies within the vast area from 73°20' to 127°50' east longitude and 33°20' to 49°48' north latitude. It starts from Binxian County, Heilongjiang Province in the east to Uzbel Pass, Xinjiang Uygur Autonomous Region in the west; and from the country's border with the Soviet Union in the north to Tianjing, the Fenhe River, Weihe River, the lower reaches of the Taohe River, the Buerhanda and the Kunlong Mountain in the south, which covers 551 counties in 13 provinces, municipalities and autonomous regions including Shanxi, Gansu, Ningxia, Qinghai, Xinjiang, Inner Mongolia, Shanxi, Beijing, Tianjing, Hebei, Liaoning, Jilin and Heilongjiang. It covers an area of 4,069,000 km^2, 42.4% of the country's total land area, of which 139,193,000 ha (account for 34.2%) are mountains and hills (including the Loess Plateau), 67,558,000 ha are plains and oasis (16.6%) and 200,159,000 ha (49.2%) are plateaus and basins (including 125,578,000 ha of deserts and Gobi which account for 30.9%). The region is inhabited by 23 nationalities with a population of 137,438,000 which makes up 13.7% of country's total, of which 111,676,000 are engaged in agriculture.

General Description of the Three Norths

The "Three Norths" is not only abundant in natural resources but also rich in its national heritage with a long history. According to historical records, the region was covered with dense forests, fertile grasslands and farmlands. But due to the wars of successive dynasties and other reasons the ecological environment deteriorated year after year, causing serious sandstorm and soil erosion. The agriculture production and animal husbandry were adversely affected and people lived in poverty and difficulty due to lack of fuel, fodder, fertiliser and timber. It became known as a region with the most harsh environment with most backward economic conditions in the country.

Forestry plays a dominant part in the land ecosystem of the earth. The area of forest resources and their distribution have much to do with the

Table 1. Land distribution of "Three Norths" region

Areas	Farmland	Forest land	Grassland	Others
Northeastern China	22.9	16.5	45.4	15.2
Inner Mongolia and Xinjiang	2.5	3.2	38.4	55.9
Loess Plateau	29.9	18.5	35.7	15.9
Northern China	26.1	25.3	29.0	19.6

natural environment which affect agriculture, livestock production and economic condition of the society. Many developed countries paid much attention to conserve and develop forest resources and likewise the Chinese government gave priority to conservation and development of forest resources. Before 1977, the natural forest area in the "Three Norths" region was only 16,947,000 ha of which scrub made up 42.6%. There were 5,896,000 ha of plantation forest, and the forested land only covered 5% of the total land in the region. The natural forests were distributed in hilly and mountainous areas of the southeast area of the "Three Norths" region, and the medium and high mountains in the west beyond the 400 mm isohyet include Tianshan Mountain, Aertai Mountain and Qilian Mountain. In the vast desert and semi-desert area, very little scattered natural secondary forest are present with trees and shrubs such as *Populus euphratica*, *Haloxylon ammodendron*, *Tamarix chinesis*, etc. The average forest cover rate of the three provinces was only 1.1-2.2%. The serious destruction of natural resources resulted in degradation of environmental conditions. The drought frequency increased from an average of once in 17 years in Qing Dynasty (1664-1800) to once in every one and a half years during the period of 1950-1975.

The "Three Norths" region is an important area for agricultural and livestock production of China. There are seven commercial grain production bases and 170 million ha of grassland in the region. It is rich in solar energy resources. The annual accumulated temperature of the days with daily temperature above 10°C amounts to 1500°C-4500°C. The annual frost free period is 100-180 days. The annual average temperature, on the whole, gradually decreases from south to north between -2.2°C and 12.1°C. The northwest part of the region, covering 58% of the total land, belongs to arid climate zone with an annual precipitation under 250 mm. The southeast part of the region is in the semi-humid zone with an annual precipitation of 400-600 mm. Between them, accounting for 10% of the total land, is semi-arid zone with 250-400 mm of annual rainfall. Most of the rainfall concentrated in summer, and there are only 10-15% of rainfall in spring (Table 1).

Establishing Protection Forest System in "Three Norths"

This project is aimed at integrated use of land resources through the establishment of the forest system to improve environmental conditions for agriculture, animal husbandry as well as fishery. The land resources will be fully used, the economic and socio-economic situation of the region will be highly promoted. The design and establishment of the "Three Norths" protection forest system were conducted under harsh natural conditions. There were frequent calamities, dislocation of agriculture, forestry and animal husbandry, and ecological balance was seriously upset. Concerning the details of the system construction, besides large scale tree planting, it also involved the work such as protecting and managing the existing forest vegetation; closing off hillsides and deserts for the regeneration of forest and grass; and also the transformation and utilisation of natural resources. As far as afforestation methods were concerned, both artificial and mechanised afforestation, air-seeding as well as closing hillsides to facilitate afforestation were adopted. The system was a huge protection compound to be built under the guidance of the theory of ecological economics. It aimed at protecting agricultural and industrial production, improving ecological environment and increasing people's income. This compound system was established on the basis of readjusting and improving the land use structure with woody plants. It included different forest types in the form of woodlands, networks and belts consisting of trees, shrubs and grasses in order to make it highly functional and multi-effective with a combined power of prevention, control and utilisation, placing agriculture, forestry and animal husbandry. This was the plan for the overall construction of the "Three Norths" protection forest system, introduced to combine closely with local conditions to improve land productivity.

The strategic goal set for the project was also to control sandstorm, water loss and soil erosion. The realisation of this strategic goal, according to the overall design, required a completion of afforestation of 35,080,000 ha and a growth of forest coverage from 5% in 1977 to 15%, and the forested area reached 60,570,000 ha, 2.6 times that of 1977. Except several bigger deserts such as Takalamakan, Gurbantunggiit, Badain Jaran, Tengger and Gobi formed in the process of natural history, the Loess Plateau, Mu Us and Holqin deserts in the "Three Norths" region was used to develop protective forest system and other vegetation. In the controlled areas, the farmland and grassland were protected by the forest system and no more serious sandstorm and water erosion will occur, and the agricultural ecosystem will move in the direction of favourite cycling. Based on the results of experiments, it is hoped that the protective forest system, after completion, will bring an increase of about 10% in crop yield and more than 20% in the output of grass fodder. The soil erosion modules will save 1,000 tons per km^2 per year. The plan for the whole "Three Norths" was divided into four primary protection forest regions, namely, the western part of northeastern China, the region of Inner Mongolia and Xinjiang, the Loess Plateau region and the northern part of northern China. The four regions were further divided into 22 sub-regions of secondary forest systems and 59 sub-regions of tertiary system. In the project design, agroforestry and other new concepts are widely used. Such a sophisticated project involves a tremendous amount of work and manpower.

Accomplishments and Effects

Owing to the joint efforts made by people of all nationalities, a total of 9,150,000 ha of area has been afforested, i.e., 831,800 ha each year which surpassed the annual afforestation plan. The forest region has been extended from 22,837,000 ha in 1977 to 31,987,000 ha at present. In addition, 2,238,000 ha of hills and mountains were also used to encourage the growth of forests and grasses, 23,000 ha of area were air-seeded for forests, and 3 billion trees planted in scattered manner. Through eleven years' of work remarkable ecological effects and considerable economic returns have been achieved through the development of farming, stock-raising and diversified economy. In some areas of the region, the sandstorm, water loss and soil erosion have been brought under control.

The forest shelter belts have protected 11 million ha of farmland which were frequently hit by sandstorm and dry hot winds in the past and the grain output has thus gone up. For instance, the farmland shelter belts built in the middle and western parts have jointly formed a large system of forest networks. Obvious changes have taken place in regional microclimate. According to the fixed spot observations made by Jilin Institute of Forestry Survey and Planning, the wind speed was reduced by 23.7% on average; the air temperature raised by 0.63°C; soil surface temperature increased by 3°C, evaporation reduced by an average of 15.2%, soil water content increased by 18.6%, and the relative humidity by 12.6%. About 40% of the planted trees in the shelter belt networks have grown into useful timber and have been involved in regeneration cutting. This has relaxed the shortage of timber, fuelwood, fodder and fertiliser.

A grassland of more than 8,800,000 ha has been established in desert and semi-desert area of the region controlling soil desertification, salinisation and grassland degeneration and the grass output has increased by over 20%. In Maowusu and Holqin deserts the forest coverage has gone up from 7% and 10% to 16.1% and 18.8% respectively since the project started. The ecological environment in the two areas has fundamentally improved greatly and now the work in the areas has entered a new stage of transformation and utilisation of desert.

In Xishui He River valley and Weibei Plateau in Shanxi Province, the forest coverage has considerably increased. The water loss and soil erosion have been brought under effective control with quite remarkable economic effect. Over 730,000 ha of fuelwood forest produced three million tons of fuelwood per year, which, combined with other energy resources, has solved the fuel problem for some five million households in the countryside. The area of economic forest has increased from 826,000-1,440,000 ha, which turned out as many as 2,750,000 kg of dried and fresh fruits valued at 2,700 million Chinese Yuan (RMB). The forest coverage of 12 cities and counties situated in the upper reaches of the Yellow River in Gansu Province, increased from 8.7% in 1977 to 12.3% and erosion controlled area covers more than 300,000 ha. In Shanxi Province, three main sand control forest belts have been established along the Great Wall, along their border area with Inner Mongolia and the foot area of the Baiyu Mountain.

Since the beginning of the project in 1978, the state and local authorities have invested 2,420 million Chinese Yuan (RMB), and a total of 1,050 million man-days spent by the people and local army units. Outstanding accomplishments have been achieved and results are remarkable. As far as the entire project of the system is concerned, this is just the first step of a "long march". But we believe that this great project, which will benefit both ours and our future generations, can be brought to a successful completion under the leadership of the Chinese government since we have support from all aspects of society and joint efforts by masses of the people in the "Three Norths" region.

Oasis Forestry in Xinjiang

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ABSTRACT

Ecological imbalances were noted in the oases of Xinjiang. The shelter belts and shelter nets composed of grass, shrubs and trees which are playing a significant role in improving the ecosystem and promoting the economic development.

Introduction

The Xinjiang Autonomous Region is located in the western part of People's Republic of China. It forms the biggest desert in China in the hinterland of the Eurasia, far from the sea and surrounded by mountains. South Xinjiang, the well-known Talimu Basin, is located in the temperate desert region, and has annual average temperature of 9-11.4°C with annual rainfall of 20-80 mm but 2,300-2,900 mm in annual evapotranspiration. In North Xinjiang, the famous Zhuenherl Basin, is situated in the cold temperate desert region, which has an average temperature of 3.6-5.7°C with annual rainfall of 100-200 mm and annual evaporation of 1,000-2,000 mm.

Xinjiang covers an area of 1,650,000 km^2 with 49.5% mountains, 28% plains and 22.5% deserts. Originating from glaciers in high mountains the precipitation rises in mid-height mountains. The 721 inland rivers stride across the whole region with a water capacity of 805.47 million m^3 which is abundant for overall development of Xinjiang. In Xinjiang, the forested land occupies 3.53% of the total land area, scattered along the rivers and in the surrounding basins. The scattered distribution of "green lands" in the vicinity of or surrounded by arid deserts, are termed "oasis". The oasis forestry shows high potential for overall development in Xinjiang and has a long history.

Existing Problems in Oasis Ecosystem

With large areas of desert, high radiation and limited water resources, as well as high pressure from increasing population, the ecosystem of oases in Xinjiang are facing a series of harsh ecological crises.

Sandstorm -

As influenced by high altitude west wind and local air current, Xinjiang often suffers damage from strong, dry hot winds. The velocity of wind is more than 18 m/s and blows for 10-30 days per year and with a gap of more than 100 days in between. These strong winds reduce wheat yield by 5-20%. The cold high pressure eddy current from Siberia hits this region strongly every other

Table 1. Nutrient contents of some shrub-grass species. (%)

Species	Fats	Protein	Fiber	Sugar	Starch	Water
Medicago sativa	2.68	11.30	33.25			
Haloxylon ammodendron	2.77	2.81	14.56	2.15	/	6.61
Caragana sp.	4.44	2.32	23.10	3.86	0.44	5.69
C.mogonum (red)	1.93	2.195	17.72	5.10	0.04	7.26
" (white)	1.80	3.15	19.20	4.16	0.52	8.83
Tamarix sp.	2.80	2.30	13.87	3.36	0.36	9.80
Alhagi sparsifolia	3.41	2.67	17.13	3.41	0.935	9.55
Astragalus adsurgens	4.09	3.38	18.04	5.28	0.16	7.93

Table 2. Wind velocity changes in different spacings of main belts

Distance between main belts	70	92	175	250	400
Belt height (m)	10	14.2	21.8	31.3	35
Wind velocity reduction (%)	52.8	50.2	38.4	29.8	25

five years and lasts one to several days at a time with a maximum wind velocity of 23.15-28.55 m/s. This strong cold wind not only takes the lives of many livestock but also causes the destruction of millions ha of agricultural crops.

Desertification -
In the arid desert areas, the strong wind erosion led to redistribution of surface materials which is a physical process extending desertification. Indiscriminate farming activities such as over-grazing and over-cutting became the critical causes for the formation of deserts in the past 30 years.

Salinisation -
Dry climate, lack of rainfall, high evaporation, leakage of irrigation systems, and over irrigation raised the underground water table. Such factors now lead to serious farmland salinisation, 66.7 million ha of farmland turned saline by 1960 and more than 100 million ha by 1980 which represents 30% of the total farmland.

The Model of Oasis Forests

The natural conditions of Xinjiang are very different from place to place, but small oases are scattered in large areas of deserts. An oasis forestry development model is suitable for Xinjiang to establish a protective forest system composed of grasses, shrubs and trees. A shrub-grass barrier is built around the periphery of oasis. Large scale windbreaks and sand-fixing forests are present around the oasis, with a shelter belt forest network in the inner oasis area intercropping and other agroforestry systems inside the networks. These forests provide timber, fuelwood and fodder.

Ecological and Economic Effects of Oasis Forestry

Shrub-Grass Barrier -
The shrub-grass barrier is the first obstruction for protecting an oasis which increases the roughness of the adjusted layer, decreases wind velocity, fixes top soil and prevents soil erosion.

With the shrub-grass barrier, 50-60 cm in height, the roughness and friction velocity were respectively 8×10^3 - 3×10^4 times and four to five times higher than those of the open area. This caused a strong raise of air from the lower layer, minimised the momentum flux downward from upper to lower layers, which reduced the wind velocity in lower layers. Wind speed is also greatly decreased inside the vegetation layer. In eroded areas, soil erosion can be controlled when the barrier's cover rate reaches at least 65%, while 40% is enough to control in the sand depositing areas. According to the observations, the blowing sand in the range of 0-20 cm in height, the shrub-grass barrier with a width of 100 m can intercept 90% of the blowing sands, and the barrier with a width of 244 m can intercept 97% of the blowing sand. Wind season and speed, sand sources, and other related factors should be carefully considered when determining the width of the protective barriers. In general, it is better to set the barrier as wide as possible, at least about 200 m. In order to preserve water balance under the desert conditions, the planting density of shrubs should not be too high. The suitable planting spacings are 2 x 5, 3 x 4 or 3 x 3 m. The planting spacings for some legumes like *Alhagi sparsifolia* and *Astragalus adsurgens* planted at the edging of the barrier could be closer. Most of the plant species used in the shrub-grass barrier are good sources of fodder. Analysis of nutrient contents of the plants (shown in Table 1) indicate that most of the widely planted high resistant, drought tolerant shrub and grass species are high nutritious fodder. The fresh leaf production from one ha of the shrub-grass barrier during winter could be enough to feed 5-12 sheep. However, it is notable that the ecological value of the protective barrier is much higher than in husbandry. Overgrazing will damage the barrier's structure and weaken the protective function.

The Effects of the Windbreaks and Sand Fixation Shelter Belts -
The windbreaks and sand fixation shelter belts around the oasis form the secondary protective barrier. If irrigation is available, sandstorm resis-

tant, tall tree species such as *Populus euphratica*, *P. balleana*, *Ulmus pumila*, *Elaeagnns* spp. are widely planted as protective forest belts. But in the water imbalanced areas, some drought tolerant shrubs such as *Haloxylon ammodendron*, *Tamarix* spp. are used instead of tree species in order to minimise water consumption by forest belts. The protective forest belts are usually 20-30 m in width. The effects of protective belts on reducing wind velocity and intercepting sand are related to the species component, structure, width and other factors of the belts.

In dense structure belts, the blowing sands begin to deposit on the windward side of shelter belts, move across the belts, and finally form a high, steep sand mount. Every 1 m of the dense structure shelter belts can deposit 12.48 m^3 sand. In the well ventilated, structured shelter belts, soil erosion is common on the windward side of the belts. The location and form of the deposited sand mount depends on the width of the shelter belt. With a 10-m wide shelter belt, the blowing sand moves through the belt and starts to deposit on the leeward at 3-4 H (height of shelter belts) and stretch with the addition of blowing sands, finally forming a 26-m wide, long, but gentle slope on the windward, short but steep on leeward mount. However, the blowing sand starts to deposit at 1/3H in windward and stretches to the leeward of the belts in the 30 m wide shelter belt.

The Effects of the Shelter Belts Inside an Oasis -

"Narrow belts or small nets" are the main forms of shelter belts established inside oasis in Xinjiang. Owing to the abundant heat, long growing season, fertile soil and good irrigation conditions of an oasis, the shelter belt trees grow very rapidly and vigorously. The most important ecological role of the shelter belts is wind reduction. The data listed in Table 2 shows that small shelter belt nets are more effective than big ones. In heavy sand affected areas on an oasis fringe, the distance of two main shelter belts is usually 15-20 H and in light sand affected areas and inside oasis, the distance is normally 25-30 H so as to form small net shelter belt systems. With their protective function, the farmland shelter belt system greatly increases crop yield and the output increase varies depending on regions. In certain regions, wheat yield could be increased by 45-117.6%; and in others by 16-29% and cotton by 24% depending on the frequency of weather. In 1987 the entire Xinjiang Autonomous Region had 187,200 ha of farmland shelter belts which not only protected 2,496 million ha of farmland, but also provided a large amount of timber and other by-products. In short, shelter belts played a tremendous role in the construction and development of the rural economy.

Table 3. Rural energy component of Shache County

Items	Time used (months)	Percentage (%)
Crops straws	5 - 6.75	42-56
Fuelwood	3.5- 7	29-58
Coal	0 - 1.75	0-15

Agroforestry in the Shelter Belts -

In order to reasonably utilise natural resources and efficiently increase crop yield in the land unit, agroforestry has become an important landuse system in the region. In 1988 only three counties had intercropped crops with trees in 563.3 ha. Beside poplar species, most of the tree species used in the intercropping system are those with high economic value such as *Amygdalus communis*, *Zizyphus* spp., *Juglans regia* and *Morus alba*. Two forms of tree planting are practised in this region. One is planting trees along the main and branch irrigation channels; the other is planting one row of trees at every 20-50 m interval. The economic benefit from this intercropping system is good. Taking Buzake Commune, Hetian County as an example, among the 14 ha of *Morus alba* plantation, 7 ha were intercropped with wheat and cotton that increased yield by 193% in wheat and 92% in cotton respectively compared with the open field.

Fuelwood and Fodder Plantations -

Fuelwood and fodder forest plantations established on wasteland and saline land are important component of forests in the Xinjiang Autonomous Region. Xinjiang is rich with coal resources, but most of it is distributed in the eastern region of northern Xinjiang. The demand is also large amounting to 18-19 million tons/year. Most parts, especially southern Xinjiang seriously lack fuel (Table 3).

Most tree species such as *Populus euphratica*, *Salix alba*, *Calligonum mongolicum*, *Haloxylon ammodendron* were usually used as fuelwood and fodder tree species before. During recent years, tree species like *Elaeagnns sp.*, *Hippophae rhamnoides* became more popular owing to their salt tolerance, high coppicing rate, soil ameliorative capacity and fast growth. For instance, Yangdaman

Commune, Shoule County established *Hippophae rhamnoides* and other fuel-fodder forests on 3,020 ha land between 1977-1984. These types of forests not only provide fuelwood and fodder but they also modify the microclimate and increase agricultural productivity. It was reported that wind velocity was reduced by 80% at 1.5 m height; daily average temperature lowered by 1.7-1.8°C; maximum temperature reduced 2.4-2.5°C; soil temperature lowered 3.8°C, and evaporation reduced by 22.2%.

Owing to the high transpiration rate of the trees, the previous logged areas were improved. It was observed that one 4-9 years' old *Hippophae rhamnoides* could transpire 20.7-26.8 m^3 of water within a growing season and thus decrease underground water level by 0.4-1.1 m. Salinisation was minimised due to the changed microclimate. Salt content in 0-100 cm below the surface was reduced by 27.8% and 79.3% in 3-4 and 6-7 years' old *Hippophae rhamonoides* forests as compared to in open fields.

Conclusion

Through the efforts and practice of more than 30 years, a suitable oasis forest model has been developed in Xinjiang and it has played a significant role in preserving the ecological balance, increasing agricultural productivity, and speeding up social development. However, further development and research of this model are needed, especially on the structure, function and species combination of the forests to provide an even more suitable oasis forest system.

Aerial Seeding on the Moving Dunes of the Maowusu Desert for Vegetation Growing

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ABSTRACT

The measurements of wind speed were conducted with 56 probes in aerial seeded land and moving sand dunes of Maowusu Desert. The wind speed distribution pattern is analysed in the paper and there was a significant difference of wind speed reduction capability among different aerial seeded species. Each species has its own geomorphological features of sand fixation. Thirteen years' intense efforts to bind sand dunes were not successful in restoring vegetation. Much longer time is needed. Aerial seeded bush planting of sand fixation should be greatly encouraged in Maowusu Desert in the future.

Key Words *Aerial seeded vegetation; moving sand dune chain; conversing effect; exploration and utilisation*

Introduction

In 1956, the first aerial seeding of Manson Pine in China was carried out in mountainous area of Wuchuan County, Guangdong Province. In 1974, a larger area was covered on the moving sand in the Maowusu Desert of arid-prairie zone. The area of seeding has been extended to more than 93,000 ha after more than ten years. Much research work on fixing the moving dunes has been done both in China and other countries. Systematic observations and studies on the process of converting shifting sand land into a stabilised one in a short period by aerial-seeded vegetation are scarce. The problem of how to scientifically manage and utilise this land reasonably has become very important and demands prompt further research to extend the aerial-seeded vegetation. The results of the present study in China are reported.

Description of the Area and Research Methods

Situated across the southern part of Yikezhao League of Inner Mongolia Autonomous Region and northern part of Shanxi Province, Maowusu Desert has a total area of 21,330,000 ha, with temperate-semiarid climate, and (annual values) precipitation of 200-400 mm, evaporation of 2,000 mm, mean temperature of 6-7°C, frost free period of 150-180 days, was mean wind velocity of 3.0-3.5 m/s. The strongest was from March to May and maximum wind velocity reached 20 m/s. For most of the year, wind blow was from northwest but it reversed its direction in June.

The distribution of sand land gradually changed from sparse shifting sand in the northwest and west into the dense one in the southeast and east. Most moving dunes were crescent-shaped with a height of 5-10 m, some reaching 20 m. The shifting sand and semi-stabilised sand interlace with densities of about 0.4-0.8 and thickness of shifting sand ranges from 7-16 cm, the thickest 27 cm. Soil moisture content was 2-4%. The Maowusu Desert is 1,000-1,400 m above sea-level. The species forming vegetation were as follows: *Agriophyllum arenarium*, *Psammochloa villosa*, *Artemisia ordosica*, *Artemisia sphaerocephala*, *Salaxis psammophylla* and few others.

To measure the effect of sand fixation, the

Table 1. Synchronised values of wind velocity on different parts of moving dunes (25 cm in height, densely-covered)

Locations of observation plots	Serial number	Values of wind velocity		Difference of two neighbouring plots
		Observed value (m/s)	Relative velocity (%)	
Windward slopes	1	3.46	75.9	0.24
	2	3.70	81.1	0.24
	3	3.94	86.4	0.28
	4	4.22	92.5	0.22
	5	4.44	97.4	0.14
	6	4.58	100.4	0.02
	7	4.60	100.9	0.16
	8	4.76	104.4	0.18
	9	5.14	112.7	0.18
	10	5.32	116.6	0.04
	11	5.36	117.5	0.28
	12	5.64	123.7	0.24
	13	5.88	128.9	0.08
	14	5.96	130.7	-0.24
	15	5.72	125.4	0.26
Tops of dune	16	5.98	131.1	0.86
	17	6.84	150.0	0.66
	18	7.50	164.4	-1.00
	19	6.50	142.5	-2.22
Leeward slopes	20	4.28	93.9	-2.48
	21	1.80	39.5	-0.18
	22	1.62	35.5	-0.16
	23	1.46	32.0	-0.02
	24	1.44	31.6	0.98
	25	2.42	53.1	0.24
	26	2.66	58.3	0.06
	27	2.72	59.6	0.12
	28	2.84	62.3	0.32
In-between dunes	29	3.16	69.4	0.20
	30	3.36	73.7	
	contrast	4.56	100	

vegetation coverage and community ability of wind reduction were considered. Seven sample plots were chosen to determine wind velocity distribution by 10 SFY 4-electron-anemometers, and vegetation coverage of 42 dunes were investigated with reference to topographic features.

Results and Discussion

The moving dune is different from flat sand land. As shown in Table 1, the mean value of wind velocity increased progressively from lower to upper points of the convex windward slope, which means that a windward slope can gather wind resulting in height increase. The intensity increased along with wind velocity. On the upper part of the windward slope the wind velocity was small and even had a negative value (observational point 15). The different wind velocities were recorded synchronously at 14 observational points along the axis of the dunes (Table 2). The wind velocities were in conformity with the distribution pattern of the dunes as observed in Table 1. However, the gradient velocities did not conform completely with wind velocity logarithm increases in proportion to height logarithm on flat sand. The distribution gradient velocities at various observational points were as follows:

1. At middle and lower points on the windward slope, the gradient velocity increased along

Table 2. Observations on wind velocity at different gradients on moving dunes

Location of observation plots	Serial number	Observational gradients of wind velocity										
		25 cm			100 cm			200 cm			300 cm	
		OV (m/s)	RV (%)	RI (%)	OV (m/s)	RV (%)	RI (%)	OV (m/s)	RV (%)	RI (%)	OV (m/s)	RI (%)
Windward slope (66 m in length, 11° slope, no vegetation)	1	2.50	76.7	11.20	2.78	71.1	7.91	3.00	70.8	6.67	3.20	72.2
	2	2.87	87.7	11.89	3.20	81.8	6.25	3.40	80.2	5.29	3.58	80.8
	3	3.18	97.5	15.09	3.66	93.6	3.82	3.80	89.6	2.10	3.88	87.6
	4	3.70	113.5	4.86	3.88	99.7	3.09	4.00	94.3	10.00	4.40	99.3
	5	3.96	121.5	10.10	4.36	111.5	11.92	4.88	115.1	-11.89	4.30	97.1
	6	4.52	138.6	4.35	4.73	120.9	9.37	4.80	122.8	-5.83	4.52	102.0
	7	5.10	156.4	0	5.10	130.4	3.92	5.30	125.0	-7.55	4.90	110.6
Top of dune (14m high)	8	4.28	13.1	9.35	4.68	119.7	6.84	5.00	127.8	1.60	5.08	124.5
	9	5.02	155.8	2.39	5.14	142.8	-0.39	5.12	131.3	-1.17	5.06	124.0
Leeward slope (31° slope, no vegetation)	10	1.12	34.5	192.9	3.28	91.1	34.70	4.42	113.3	4.07	4.60	112.7
	11	0.70	21.5	5.71	0.74	20.6	32.43	0.98	25.1	63.33	1.60	39.2
	12	1.52	46.6	-2.63	1.48	41.4	58.10	2.34	60.0	-10.26	2.10	51.5
	13	1.32	40.5	15.16	1.52	42.2	4.21	2.80	63.1	-12.14	2.46	60.3
In-between dunes	14	2.38	73.0	5.04	2.50	69.4	13.60	2.84	12.8	-5.63	2.68	65.7
Contrast		3.26	100.0	19.93	3.91	100.0	8.43	4.24	100.0	4.48	4.43	100.0

with height.

2. At middle and upper points (Nos. 5-7) on the windward slope, the gradient velocity increased along with height at the outset, then decreased.
3. At middle and upper points (Nos. 10-11) of the leeward slope, the gradient velocity increased with height and in some (Nos. 12-13) it increased first and later decreased.

The gradient is within 3 m. With continued height increase, the gradient wind velocity decreased because the observational points moved away gradually from the control of the wind-gathering effect. Gradient velocity at middle and upper points of the leeward slope was affected directly by high speed wind on the top of dune on the windward slope, especially when the observational point was above the top of the dune. The reason of gradient velocity at the lower part of the leeward slope became higher at the outset and slower afterwards, along with height increase was that observational points had approached the center of cyclonic-turbulence. Wind velocity at the periphery of the air mass of cyclonic-turbulence was greater at upper parts because it was accelerated by strong winds on the top of dune, slower at lower parts because of the frictional force of earth's surface. Therefore, the wind velocity in both "horizontal" and vertical directions was affected by the height and length of the slope. This was the first time that a large scale, systematic and synchronous observation was made on a moving sand dune.

The Effect of Wind Reduction of Sweetvetch Bush and *Hedysarum monglicum* Bush -

The maximal and minimal values of wind reduction of sweetvetch bush were observed on the windward slope outside of the bush (Table 3). The lowest wind velocity appeared at 6 m behind the bush with a relative velocity to the control of 20% (Table 3, No. 13). This showed that sweetvetch bush land was very uneven. Wind velocities on *Hedysarum monglicum* bush land at all observational points, including the top of dune, did not exceed those on the controls on flat sand land. This shows that the wind reduction of *H. monglicum* bush land was well distributed and without high tops. If we compare Sweetvetch bush with *H.*

Table 3. Observations on effect of wind reduction in Sweetvetch and H. monglicum on dunes

Serial number	Sweetvetch Seeded in 1975		*H. monglicum* seeded in 1975		Remarks
	Location of observational point	Relative wind speed (%)	Location of observational point	Relative wind speed (%)	
1	Foot of windward slope outside bush	43.78	Sparse *H. Monglicum* Bush Land	42.10	Spaces between 2 points: 2 m for Sweetvetch and 2.5 m for *H. monglicum* Height of observational points: 25 cm.
2		49.43		39.80	
3		49.60		32.40	
4	Inside Bush	31.00		40.24	
5		32.55		30.87	
6		29.16		42.50	
7		30.35		39.90	
8		23.95		41.80	
9		35.26		49.90	
10		33.01		53.02	
11		26.67	Terrace inside Bush	51.44	
12	Behind Bush	25.27		42.26	
13		18.21		32.67	
14		27.48		31.95	
15	Terrace on slope behind bush	40.07		47.48	
16	Windward slope even up behind Bush	44.10		53.38	
17		50.36	Uncovered windward slopes even up behind Bush	59.66	
18		58.72		48.83	
19		68.09		83.78	
20		76.70		79.40	
21		73.50		71.40	
22		90.70		59.17	
23	Top of dune	105.40	Top of dune	71.88	
24		88.54		54.22	
25		104.19		57.08	
26	Leeward slope	50.41	Leeward slope	27.72	
27		22.30		20.88	
28		36.52		24.20	
29	Foot of slope	45.52			
30	Space between dunes	39.07			
Contrast		100		100	

Table 4. Observations on effect of wind reduction at different gradients of Sweetvetch and *H. monglicum* on dune

Serial number of obser-vational points	Observation on wind-reducing effect of Sweetvetch seeded in 1975 (windward slope 11°, 60m in length, leeward 31°, dune height 50m, vegetation 27.07%)					Observation on wind-reducing effect of *Hedysarum monglicum* seeded in 1975 (windward slope 8°, 73m in length, leeward slope 33.5°, dune height 6.5m, vegetation 30.08%)				
	Location of observational points	Relative wind velocity on different observational gradients (%)				Location of observational points	Relative wind velocity on different observational gradients (%)			
		25cm	100cm	200cm	300cm		25cm	100cm	200cm	300cm
1	Windward slope outside bush	40.54	49.42	53.84	58.26	Bush land	35.84	42.36	46.80	51.42
2		32.12	48.80	54.18	58.76		38.52	47.64	58.50	58.72
3	Inside bush	25.61	47.28	57.58	67.00		44.36	53.06	61.82	62.98
4		33.91	70.69	76.02	106.96		55.96	62.60	69.78	70.34
5		36.98	55.70	68.24	77.36		51.02	71.92	76.28	76.98
6		30.84	57.52	68.26	80.36	Terrace inside bush	41.86	64.34	69.64	77.48
7	Windward slope even up behind bush	11.69	22.78	52.68	75.18		59.96	56.94	61.16	71.54
8		43.48	47.66	62.05	73.55		83.30	85.22	80.58	90.68
9		45.47	60.88	67.52	73.93	Windward slope even up behind bush	85.76	92.92	94.46	95.56
10		58.84	61.84	73.38	81.46		91.58	92.04	94.42	98.52
11		105.86	93.98	94.76	118.60		88.42	106.68	106.72	106.54
12	Top of dune	109.42	97.56	94.62	94.94	Top of dune	62.10	97.21	105.10	107.56
13	Leeward slope	12.90	19.02	34.96	78.51	Leeward slope	58.04	39.87	56.04	88.82
14		31.34	27.56	25.90	23.96		67.60	29.02	28.63	38.52
Contrast		100	100	100	100	Contrast	100	100	100	100

monglicum bush, the latter functioned better in the transformation of sand land. The values for two bushes did not increase along with distance between observational points, while wind velocity was reduced regularly. The reason was that the distribution of vegetation was uneven. The accumulated sand in the center of the bush was usually higher, forming a small terrace of several square meters with little or no vegetation, which enabled the wind velocity there to be greater as it was in Nos. 10 and 11 with *H. monglicum* bush. The distance of wind reduction out of the fringe of the bush was 9 m in Sweetvetch bush and maximum reduction was 6 m outside the bush (No. 13). But the biggest wind reduction in *H. monglicum* bush was No. 5. This showed that the accumulative sand of *H. monglicum* bush formed a small leeward slope while the land was still relatively flat behind the bush.

The wind velocity of "horizontal" points was disrupted completely by bush vegetation and the values of wind velocity were larger both "horizontally" and vertically in Sweetvetch bush land and reduction at 25 cm in height was remarkable. The capability of reducing wind at 25 cm in height of *H. monglicum* bush land was approximate to that at 100 cm of Sweetvetch bush land (Tables 4 and 5). The height of Sweetvetch bush was more than two times that of *H. monglicum.* The major species were *Corispermum hyssopifolium*, *Artemisia ordosica* and four others. The plants of *Hedysarum monglicum* were dense resulting in relatively less plant invasion and the major species was *Psammochloa villosa*, *Agropyron monglicum* and *A. ordosica.* The seedling of Sweetvetch bush and *H. monglicum* were simultaneously distributed in 1975 but they shrank due to intense wind erosion in the first few years. The accumulative sand was thicker and very well preserved. The width of Sweetvetch bush is 19 m (Table 4, Nos. 3-6), and hardly ever widened. The height of accumulative sand increased and formed bush land of terraced shape or "isolated island" shape. This physiognomy was retained even after 13 years. *H. monglicum* bush land, reduced in width by wind erosion at first later expanded to a width of 35 m

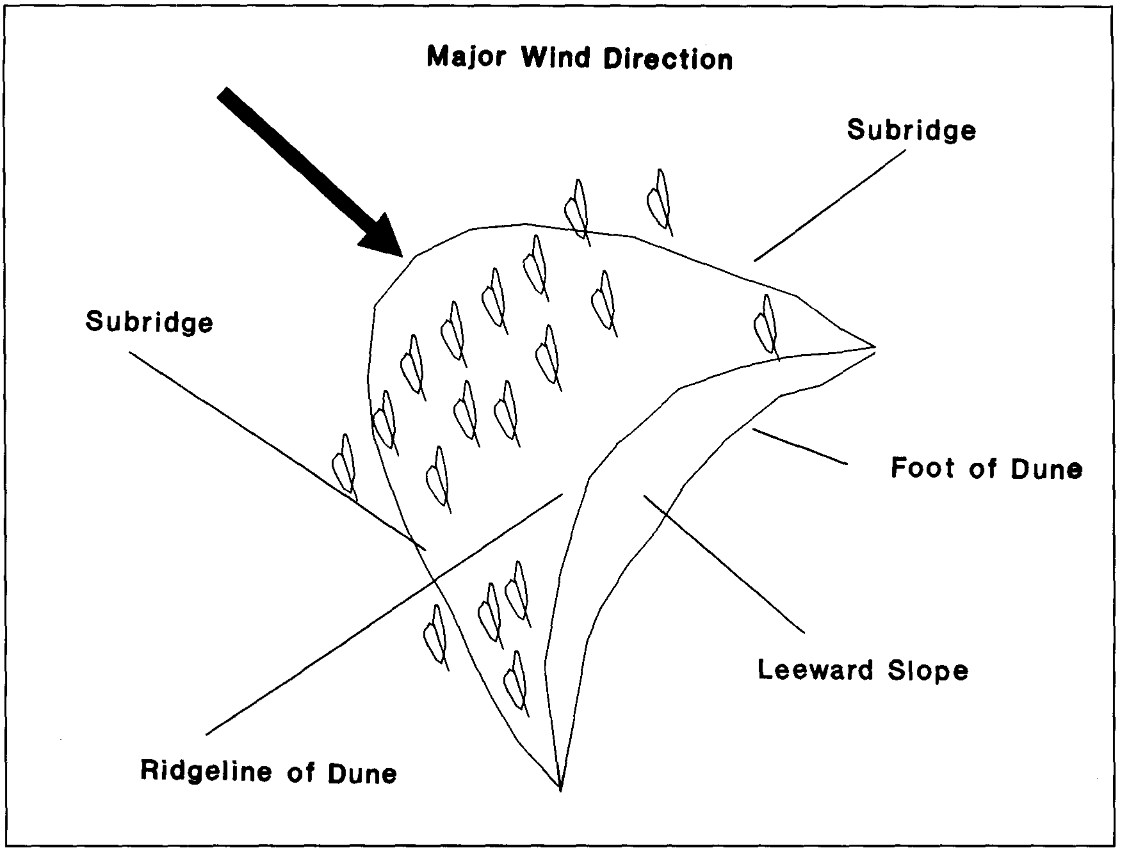

Fig. 1 *Distribution of serial-seeded young plants*

(Table 4, Nos. 1-8). Many saplings sprouted from subterraneous stems. The shape of windward slopes has become less acute as a result of the expansion of bush land. Therefore it is not sufficient to evaluate the sand fixation ability of vegetation only by means of wind reduction ability. Sand fixation ability is determined mainly by the adaptability of the species to the shifting sand.

Compared with the aerial-seeded dunes, the moving sand dunes (not aerial-seeded but closed to livestock and any other human activities) in the control plots did not have any vegetation left in both the windward and leeward slopes after 13 years. Compared with the flat sand land, the accumulated value of wind reduction percentage in different gradients appeared to be negative on the windward slope. It shows that wind velocity on the windward slope was greater than that in flat sand land, so its wind erosion susceptibility was also greater. The wind velocity on the leeward slope was much slower than that on the flat sand land, which lead to the accumulation of a large quantity of sand. The serious sand erosion and heavy sand covering were unfavourable for plant invasion and growth. The result of enclosure for 13 years showed that the restoration of vegetation on moving dunes can hardly succeed, therefore, are not recommended for the Maowusu Desert in the future. On the contrary, seeding by aircraft should continue.

The Process of Moving Dune Fixation by the Aerial-seeded Vegetation -

From the above results and analysis, it was seen that wind reduction benefits depend upon community density and height of the air-seeded plants. In addition, wind reduction performance was determined by the composition and growth conditions of invading vegetation and other factors such as the constantly changing topographic features of aerial-seeded land. Based on the numerous experiments and investigations, we can now explain in detail the process of moving dune fixation, taking *H. monglicum* as the most suitable species. *H. monglicum* was seeded by aircraft on medium height crescent dune chains (7-10 m in 1977). Survival rate was 37.7% in the first year, with no seedlings on the leeward slope of a dune or a subridge (Fig. 1). The width, length and distribu-

Table 5. The percentage cumulative value of wind reduction between bush land and moving dune

Observational gradients	Sweetvetch seeded in 1975		Hedysarum monglicum seeded in 1975		Control of moving dune	
	Windward slope	Whole dune	Windward slope	Whole dune	Windward slope	Whole dune
25 cm	634.66	781.00	415.28	539.12	-91.89	109.61
100 cm	483.18	639.04	330.94	467.16	-43.61	161.41
200 cm	380.49	516.37	256.34	370.05	-3.54	172.80
300 cm	247.18	349.79	245.83	304.39	40.08	227.52
Total	1745.41	2286.20	1248.39	1681.17	-98.96	671.40

Note: "Whole dune" means all observational points on the top of dune and leeward slope.

tion position of *H. monglicum* in the shape of a crosswise belt on the windward slope depended upon the characteristics of wind erosion and accumulative sand on windward slopes. This crosswise belt distribution changed "green belts" on windward slopes in terraced shapes. The vertical "green belt" was formed when seedlings suffered less wind erosion. However, within three to four years, due to increased growth and the decline of wind erosion on vegetation, typical changes took place on the seedling survival rate per given area and topography of the sand land changed. The survival rate was only 17.4%. Other plants such as *Agriophyllum squarrosum* and *Corispermum hyssopifium* colonised. The horizontal "green-belts" were eroded by wind erosion separated into several "green-belts" and "green-isolated-islands" of different sizes, the land between them formed "wind erosion troughs" with widths ranging from several to more than 10 m. The plants grew luxuriantly, the density and height increased. So the overall effect on wind reduction increased progressively which was shown by the fact that even though the top of the dune was scrapped again and again, the concave leeward slope pushed forward. The height of the dune was evidently lowered every year, the land area between dunes was reduced, the ratio between the areas of the windward and leeward slopes became larger (the normal is 3:1) the length of the windward slope became longer and the gradient smaller; the length of the leeward slope became bigger and gradient smaller; the velocity of "tongue-shaped" dunes (not the whole dune) became larger; the surface of the windward slope was cut into pieces; the survival area rate of seedlings was smaller than at the beginning. Apparently, the prospect of sand fixation was quite poor but there was a substantial change. The settled aerial-seeded *H. monglicum* vegetation created suitable conditions for its survival under sand cover and became the base for further expansion. Some *H. monglicum* began to bear seed in the second year, a few seedlings appeared nearby, with many subterraneous stem sprouts. *H. monglicum*, seeded in 1977 and investigated on July 17, 1988, grew 1.6 m/yr in 1987 and 1988, with each stem sprouting five or six young plants. The survival area rate in 1977 was 37.7% for the first year and 17.4% in 1988, but more than 60% in 1986. The topography of the aerial-seeded land changed. Some sand slopes, covered with vegetation and bryophytes, caused surface runoff after rainfall (33.1 mm) in the wee hours on July 7, 1988. This phenomenon was never seen before on moving sand. With the expansion of the aerial-seeded acreage, it is very important to manage and utilise the aerial-seeded land for ecological, economic and social benefits (Table 5).

Aerial-seeded Land is High-quality Pasture -

In the natural pasture of Maowusu Desert, the major plants are herbs which provide edible biomass 10-17 kg/ha. The bush of aerial-seeded *H. monglicum* at the age of 13 years with a coverage of 43.5% produced 41 kg/ha/yr of edible biomass, which was three or four times more than that of natural pasture. The bearing of aerial-seeded bush *H. monglicum* at the age of 5-8 years after artificial rejuvenation by cutting, increased by 45.7-77.1%, and the fresh weight increased by 64.4%. The herdsmen call the aerial-seeded *H. monglicum* "lucerne", on the desert. The draught animals like it because it suits their palate. The crude protein content of annual branch of *H. monglicum* is 20.35%; Sweetvetch 16.46%; little leaf peashrub 13.54%. The digestible rate of crude protein of *H. monglicum* in sheep was 77.44%; more than that of

Sweetvetch's 75.39% and little leaf peashrub's 56.71%. The branches and leaves of *H. monglicum* can be processed into grass powder. Through controlled experiments of feeding sheep using 66.7% of this powder with others, the result revealed that the increment of weight of sheep was nearly equal to the control. So the powder of *H. monglicum* also solved the problem of storing fodder to meet the shortage. 10,000 mu (equal to 667 ha) of *H. monglicum* bush can supply peasants and herdsmen with about 1,033,800 kg fresh grass and 350,000 kg firewood. The fodder can maintain 1,500 draught animals.

The Aerial-seeded Bush can offer Multi-level Forestry Business -

The changes of ecological environment have taken place in sand land after shifting sand had been stabilised or semi-stabilised through aerial-seeding. As a result, the changes of physical and chemical properties have followed. Clay content was 3.5-4.8 times as much as before. The clay that was deposited in the litter of the decomposition and the semi-decomposition layer shaped progressively into "crust" in combination with bryophytes. The "crust" played an important role in conserving water and improving soil. The organic matter was 39.1-49.5% times that of shifting sand land; the total nitrogen increased 5-6 times; and phosphorous 3.7-4 times. The water condition deteriorated because the sand coverage increased. But the open and uncovered parts were blown flat and became naked on upper windward slope. Its water content was nearly equal to that of shifting sand. There is no wind erosion, and they became ideal places to plant pure forest of small area or mixed forest on a large scale. The suitable afforestation species are scotch pine (*Pinus sylvestris* L. var. *mongolica* Litv.), Chinese pine (*Pinus tabiclaeforwis* Carr.), Siberian Elm (*Ulmus pumila* L.), black locust (*Robinia pseudo-acacia* L.), and Hebei poplar (*Populus hopeins* Hu et Chou). These species can grow and develop normally in stabilised and semi-stabilised sand land formed by aerial-seeded vegetation.

Cultivation and Utilisation of Agribush in Inner Mongolian Region

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ABSTRACT

This paper deals with the bio-ecological properties and cultivation techniques of Mongolian willow (Salix monglica) and little leaf peashrub (Caragana lam), two species of agribush, under arid condition in Yikezhao League of Inner Mongolia Autonomous Region. Problems connected with large scale cultivation are discussed.

Key Words *Bio-ecological properties; Salix monglica; Caragana lam; cultivation technique; economic and ecological effects; agroforestry*

Introduction

Yikezhao League of Inner Mongolia Autonomous Region is situated in an arid-prairie zone, gradually changing into desert zone in the west. Formerly this was a pure stock raising district. Agriculture was introduced and developed only in the past hundred years, livestock farming has been the main part of its agriculture as well as the mainstay of the league's economy. The progress of stock raising development depends to a large extent on forestry and plants grown in this area. Without forestry as its base, there would be neither stabilised livestock farming nor any agriculture development. Therefore, the afforestation programme is implemented with shrub as the major and tree combination. We have studied the utilisation of two main agribush species Mongolian willow and little leaf peashrub to develop them.

Description of the Area

Yikezhao League covers a total area of 86,386 km^2 between the latitudes of 37°25'42" and 40°51'40"N and the longitudes 106°30'00" and 111°27'20"E, bordering Shanxi Province in the south, and its other three sides being surrounded by the Yellow River. It has a typical continental climate, and temperature can reach a maximum of 76.7%. The natural features are as follows:

Arid and Little Rain -

Precipitation ranges from 440 mm in the east to 150 mm in the west annually, and the rain falls, often rainstorms, mainly in July, August and September (60-70% of the total). Annual evaporation capacity ranges from 2,106 mm in the east to 2,715 mm in the west, five to seven times as much as the rainfall. So natural disasters such as drought and flood often occur. The number of floods is far less than that of droughts, so there goes the saying, "nine droughts in ten years".

Strong Wind and Much Sand -

The south of the area is the Maowusu Desert and in north the Kubuqi Desert, and the area is subjected to most serious desertification. The desertified area above medium degree measures 43,267 km^2 or 50.1% of the total area, the unproductive land amounts to 27,666 km^2 or 32% of the total. Mean wind speed in a year is 2.1-3.8 m/s and the maximum can be 28.7 m/s. Annual mean number of days with wind or gale force is 17-35, mainly in spring and strong winds cause calamities.

Serious Soil Erosion -

The area of soil erosion with simultaneous desertification in some parts is 47,298 km^2 or 54.7% of the total area. The land is broken into gullies and ravines and the terrain is rather rugged. Annual modules of erosion is 18,900 km^2, total soil

Table 1. Nutrient contents of the two agribush species.

Species common name	*Salix monglica*		*Caragana lam*	
Phenophase	Blossom	Stoke	Blossom	Stoke
Water	8.10	12.34	8.40	-
Crude protein	12.63	13.79	25.09	12.54
Crude fat	6.20	14.32	4.07	3.23
Crude fibre	32.70	27.47	23.30	32.36
Nitrogenless extract	-	27.04	36.81	44.09
Crude ash	4.16	5.04	4.93	7.87
Ca	1.00	3.08	1.15	-
P	0.50	0.64	0.33	-
Carotin (mg/kg)	26.87	31.75	-	-

loss 176 million tons, of which 150 million tons are washed out by the Yellow River.

Violent Change in Temperature and Long Sunshine -

Annual mean temperature is 5.7-7.4°C. Winter is long and cold, summer short and hot. Daily range of temperature is well over 10°C, in some areas it reaches 31°C. Annual sunshine time is 2,890.6-3,212.9 hours with solar radiation of 100-160 kcal/cm^2. It is one of the longest sunshine time areas in China. The plant growth period is 143-177 days and vegetation sparse.

Utilisation of Agribush and the Benefits

Planting of Mongolian willow and little leaf peashrub began in 1960s in Yikezhao League, and its large scale planting in 1980s. In 1985, the area of Mongolian willow bush was extended to 212,260 ha, while the natural area was 52,110 ha, totalling 264,370 ha. They produced 1,275 kilotons of twigs and annual output was 445 kilotons. The area of cultivated grassland of little leaf peashrub was 404,000 ha, while the natural was 441,780 ha, total 846,500 ha.

The bush planting over years has played an important role and achieved great economic, ecological and social benefits supporting livestock farming, agriculture, forestry, water and soil conservation and comprehensive utilisation of the land.

Livestock Farming Development -

The tender branches and leaves form good fodder and are nutritious (Table 1). They are classified as emergency herbage in the grass shortage season during winter and spring, and during the seasons of strong wind and snow, they play an important role in protecting livestock.

Utilisation of Bush-grassland -

The Mongolian willow grassland was 154,000 ha in 1985 in Yikezhao League or 50% of total Mongolian willow bush area and 96,000 ha of grazing land. One million heads of sheep were brought there, amounting to 21.3% of the total of 4,698,000. The livestock eat the tender branches and leaves and the herbage under the bush which are edible and in no need of processing with 526,500 kilotons forage of the branches and leaves available per year. If the eating rate was 70%, 368,550 kilotons would be provided for 237,800 sheep units. Counting by 30 Chinese Yuan (RMB) per ton, its total value would be 11,057,000 Chinese Yuan (RMB). While the bush grass can keep off the wind, the temperature is higher than that of open land, which is favourable to the livestock to live through the winter. The total area of the grazing land protected by the bush is 300,000 ha. The output of the grazing grass is 20% higher than general. The annual output increase 100,000,000 kg is valued at 3,000,000 Chinese Yuan (RMB). It can provide 44,500 sheep units with forage.

The output of fresh grass of little leaf peashrub is 540-1,230 kg/ha, three times that of the former. Every 2.3 ha of grazing land on an average can feed one more sheep unit. The grazing land was improved by little leaf peashrub of 6-7 years is 982.5-1,237.5 kg/ha, four times that of the former, every 1.7 ha can feed on an average one more sheep unit. The output of fresh grass in grazing lands improved by the bush of ten or more years, 2,197.5-2,640.0 kg/ha, ten times that of the former, every 0.9 ha can feed on an average one more sheep unit. The output of fresh grass of artificial and semi-artificial grazing land was 600,000 kilotons, 591,450 kilotons more than that of the former. If the eating rate was 60%, it would be 384,440 kilotons, increasing the livestock by 267,000 sheep units, the increasing rate of carrying capacity was 87%, valuing at 0.03 Chinese Yuan (RMB) per kg, it makes 11,533,000 Chinese Yuan (RMB) in total.

A Study on *Elaeagnus angustifolia* for Fuelwood and Fodder in Arid Zone

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ABSTRACT

In northwest China, there are vast arid and semi-arid areas. The vegetation covers are very sparse with serious shortage of fuelwood and fodder. The results of five-year experiments have shown that the E. angustifolia is not only a fine fuelwood species with high yields and high sprouting ability, but also a promising fodder species with high nutrition value. The growth responses of E. angustifolia to planting spacings and rotations are discussed in this paper.

Introduction

In China, the biomass energy constitutes 68.7% of rural energy consumption, of which fuelwood is 276 million tons. The supply and need situation of fuelwood varies from place to place. In the arid and semi-arid regions of northern China, the fuelwood deficit is outstanding because of harsh natural conditions, sparse distribution of vegetation and lack of fuel. The overuse of the land in the region has increased the desert area to 0.17 million km^2 and eroded area 0.28 million km^2. Of these, 1/3 of total desert area is effected by over cutting for fuelwood. In order to protect the fragile ecological environment and alleviate the fuel deficit, this study began in 1983. There is also a deficit of livestock fodder in the region. Many fuelwood trees provide good fodder. The solutions to the fuelwood and fodder deficit are common and the economic development of rural areas can be promoted.

Materials and Methods

Site Description -

Denkou (106°53'-106°59'E, 40°17'-40°29'N) is located in Bayannaoer Prefecture of Inner Mongolia, northeast to Wulanbuhe Desert, west to the Yellow River, with temperate and dry desert

Table 1. Comparison of biomass production of ten fuelwood species, all 5 years old.

Species	Spacings (m)	Biomass production: Total (kg/tree) Fresh	Dry	Fresh leaves (t/ha)	Fuelwood yield (t/ha)	Calorific (cal/g)
Salix psammophylla	2 x 3	18.3	8.3	3.164	13.8	4439
Hedysarum scoparium	2 x 3	14.6	5.7	2.331	9.5	4728
H. monglicum	2 x 3	8.2	4.8	1.665	8.0	4675
Tamarix chinensis	2 x 2	11.2	5.5	1.998	9.2	4500
Elaeagnus angustifolia	2 x 2	13.8	6.1	2.997	15.3	4508
Hippophae rhamnoides	2 x 3	12.9	5.8	2.664	9.7	4524
Caragana korshinskii	3 x 3	12.9	6.9	2.498	7.7	4987
C. microphylla	2 x 3	7.8	4.0	1.590	6.7	4788
Haloxylon ammodendron	3 x 3	15.4	9.3	3.330	10.3	4461
Amorpha fruticosa	3 x 3	13.8	6.4	2.414	7.1	4361

Table 2. Multiple range test of fuelwood production at different planting spacings

Planting spacings (m)	1985 Fuelwood (t/ha)	1985 Homogeneous groups 5%	1985 Homogeneous groups 1%	1986 Fuelwood (t/ha)	1986 Homogeneous groups 5%	1986 Homogeneous groups 1%	1987 Fuelwood (t/ha)	1987 Homogeneous groups 5%	1987 Homogeneous groups 1%	1988 Fuelwood (t/ha)
1 x 1	3.44	b	A	8.59	ab	A	12.74	b d	A C	13.44
1 x 1.5	3.04	b	B	6.61	b	A	7.68	c	B	9.36
1 x 2	4.38	ab	AB	13.31	a	A	21.33	a	A	22.62
2 x 2	6.06	a	A	12.06	ab	A	14.74	b	A	16.27
2 x 3	2.66	b	B	8.69	ab	A	10.36	bc	AB	12.11

Table 3. Fuelwood production of plantations with different spacings at cutting ages of 2,3,4 Years

Spacings	1 x 1			1 x 1.5			1 x 2			2 x 2			2 x 3		
Year	Bio-mass t/ha	Homogeneous group 5%	1%	Bio-mass t/ha	Homogeneous group 5%	1%	Bio-mass t/ha	Homogeneous group 5%	1%	Bio-mass t/ha	Homogeneous group 5%	1%	Bio-mass t/ha	Homogeneous group 5%	1%
1987	12.74	a	A	7.68	a	A	21.33	a	A	14.74	a	A	10.36	a	A
1986	8.59	ab	A	6.61	a	A	13.31	b	A	12.06	a	A	8.69	a	A
1985	3.64	b	A	3.04	a	A	4.38	c	A	8.69	b	A	2.66	b	A

Table 4. Comparison of biomass production of various spacings, all 4 years old

Spacings	1 x 1			1 x 1.5			1 x 2			2 x 2			2 x 3		
Period and items	Bio-mass t/ha	Homoge-neous group 5%	1%	Bio-mass t/ha	Homoge-neous group 5%	1%	Bio-mass t/ha	Homoge-neous group 5%	1%	Bio-mass t/ha	Homoge-neous group 5%	1%	Bio-mass t/ha	Homoge neous group 5%	1%
1984-1987, Stem & branch	12.74	b	B	7.68	c	B	21.33	a	A	14.74	b	A	10.36	bc	B
1984-1987, Mean annual	3.19			1.92			5.33			3.69			2.59		
1987, Leaf dry weight	2.17	a	AB	1.77	ab	AB	2.48	a	A	1.21	b	B			
Annual increment	5.36	b	A	3.69	b	A	7.81	a	A	4.90	b	A	3.88	b	A

climate. The maximum temperature is 32.7°C, minimum -23.1°C; mean annual precipitation 137 mm; annual evaporation 2,351.9 mm, 16 times more than the precipitation. The annual solar hours are more than 3,000 hours, relative humidity 47%, frost free period 168 days and mean annual wind speed 3.1 m/s.

The experimental plot is on a desert with underground water table of 2-3 m generally. The total salt content of the soil is 0.18-0.20% with pH value of 8.9-9.4, soil depth 0.3-0.5 m. The natural vegetation coverage rate is 15-30% with the main species - *Nitraria tangntorum*, *Artemisia sphaerocephala* and *Pasammochloa mongolia*.

Materials -

Before the establishment of the experiments, a fuelwood species survey was conducted in Dengkou area (see Table 1). *Elaeagnus angustifolia* was found to be higher in biomass production and it was selected for experiments.

Methods -

Two experiments (spacing trials and rotation

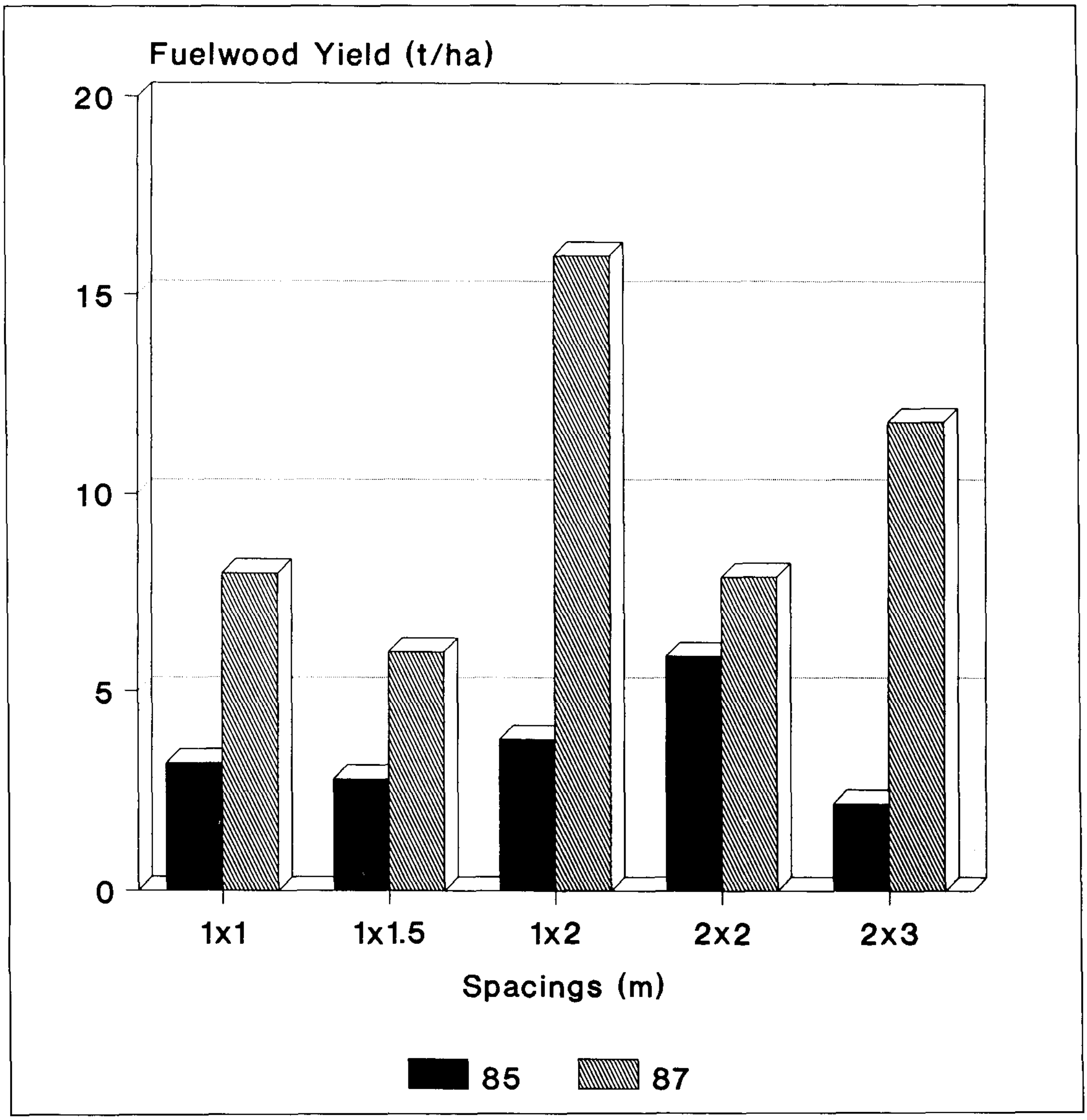

Fig 1. Comparison of fuelwood yields of the first two rotations

Table 5. Calorific values of *E. angustifolia*

Year of test	Spacings or Parts	Calorific values (cal/g)
1986	Stem,branch	4340
1987	1 x 1 m	4450
	1 x 2 m	4470
	2 x 2 m	4460
	2 x 3 m	4440
1987	Stem	4500
	Branch	4360
	Leaf	4290

trials) were included and the spacing trials were 1 x 1, 1 x 1.5, 1 x 2, 2 x 2 and 2 x 3 m, and periods for cutting cycle (rotations) were 2, 3, 4, and 5 years respectively for each of the spacings. The growth monitoring (tree height, diameter at ground level, crown diameter, etc.) and biomass investigation were also conducted. The calorific values of stem and leaves were tested and the main nutrient components of leaves were analysed. Statistical analysis of Duncan New Multiple Range Test was used to explore the responses of growth and biomass production to planting spacings and rotations.

Table 6. Comparison of nutrient contents between *E. angustifolia* and alfalfa.

Species	Crude protein (%)	Crude fat (%)	Crude fiber (%)	N-free extract (%)	Ash content (%)	Water content (%)
Elaeagnus angustifolia	18.58	6.59	20.75	29.45	7.39	7.14
Alfalfa	18.6	2.4	35.7	34.4	8.9	

Results and Analysis

High planting density with short rotation is an important method to increase biomass on unit land. It is very important to determine the suitable planting spacings and rotation in development of fuelwood and results are listed (Table 2). The spacing of 1 x 1.5 m has the lowest fuelwood yields, with 1/3 of the yields of 1 x 2 m. In 1985, although the 2 x 2 m had highest yields, the difference with 1 x 2 m was not significant. In 1986, there were no significant differences between the spacings. It can be concluded that, at the same site conditions, the obvious difference in fuelwood yield is caused by the planting spacings and the spacing of 1 x 2 m was the best one.

Biomass Output at Different Cutting Ages - The fuelwood yields from the plantations with different spacings at cutting ages of 2, 3, and 4 years old are listed in Table 3 and there was significant difference in fuelwood yields between 1987 and 1985, but no significant differences in four spacings between 1987 and 1986 except the 1 x 2 m spacing. It shows that the earliest cutting can be the age of three years, but if a maximum biomass production is to be obtained, cutting at the age of four years is the optimum. As for the above ground biomass, cutting at age four, the fuelwood yields of 1 x 2 m plantation is 21.33 t/ha (see Table 4), which is far higher than those of other spacings.

It can be seen from Fig. 1 that the second cuttings had higher biomass, and the difference of fuelwood yields of the second cuttings existed between various spacing treatments. For the net growth of fuelwood in one rotation (two years), the 1 x 2 m spacing was 10.66 t/ha, with an increase of 243%; the 2 x 3 m spacing was 9.5 t/ha or 357% increase. The calorific values of *E. angustifolia* at different ages and planting spacings vary from 4,340-4,500 cal/g (Table 5).

Nutrient Components and Fodder - The fuelwood plantation of *E. angustifolia* entered a high yield stage at four years after planting with high output of foliage also. The annual fresh leaf yields were 5.42-6.22 tons/ha, good potential sources of fodder. The analysis of nutrient components (see Table 6) shows that the foliage of *E. angustifolia* contains 18.58% crude protein, which is close to that of a good fodder species of alfalfa.

Conclusion

Elaeagnus angustifolia is a good fuelwood species in arid areas of northern China. It grows fast, has high calorific value and can be utilised continuously with large amount of fuelwood obtained in a short time. Leaves contain rich crude protein, crude fat and is a suitable species for fodder production.

IV. AGROFORESTRY SYSTEMS IN SUBTROPICAL ZONE

Bamboo (Phyllostachys pubescens) - Paulownia (Paulownia fortunei) Mixed Plantation (Tongling, Anhui)

Pear (Pyrus) - Tea (camellia sinensis) Interplanting (Tongling, Anhui)

An Ebidle Fungus (Auricularia auricula-judae) cultured under Paulownia

Pecan (Carya illinoensis) - Tea (Camellia sinensis) Interplanting

A Study on Integrated Silvi-agriculture Management

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ABSTRACT

The agroforestry systems which have been established in Lixiahe region, are forestry-fishery-agronomy, forestry-fishery-animal husbandry, forestry-aquatic crops-fishery, forestry-fishery, forestry-agronomy, forestry-edible fungus, etc. The net profits of agroforestry systems are 10-30 times higher before exploitation or 1-2 times higher than monoculture of forest or pure farming system. Agroforestry practices also improve the environmental conditions, enhance the ecological stability and expand employment.

Introduction

The integrated silvi-agriculture project experimental area is situated in Lixiahe region (32°42'-33°06'N and 119°15'-120°51'E), known as a region of rivers and lakes, in the middle part of Jiangsu Province. The altitude above sea-level ranges from 1-5 m, average annual rainfall 1,000 mm and swamp soil.

The study was started in 1982 and the following major agroforestry systems have been established - forestry-agronomy, forestry-fishery-animal husbandry, forestry-fishery, forestry-aquatic crops-fishery, forestry-agronomy and forestry-edible fungus. Before exploitation, the wasteland had only reeds and weeds, with the gross profit of only $80-$160 per ha. The profits of agroforestry practices are 10-30 times before exploitation and ecological conditions have improved.

Types of Agroforestry Systems

Forestry-Fishery-Agronomy -

This is used in wet land with high water table and to lower it, ditching and terracing are commonly used. The ponds are constructed on one side and terraces on the other by removing the soil from the moist land. Trees are planted on the terraces, fish raised in the ponds, and crops interplanted forming an integrated biological production system.

There are three types of this system depending upon the management purpose and the width of terraces and ponds: (1) The width of ponds ranged from 2-5 m and the width of terraces from 10-15 m. This was used to raise shrimp, fish and fish fry. (2) The width of ponds ranged from 5-10 m and the width of terraces from 15-20 m. This type of pond was used to rear fishes extensively. (3) The width of ponds ranged from 15-20 m and the width of terraces from 20-40 m. This type was used to raise fish intensively. The major tree species were *Taxodium ascendens* and *T. distichum*, etc. The major intercrops were rape, wheat, barley, soybean, taro, strawberry, cabbage, radish, daylily, watermelon, broad bean and cotton. The major fishes were silver carp, grass carp, black carp, crucial carp and shrimp.

Forestry-Agronomy -

This system was on the land where the water table was lower than 0.5-0.8 m from ground surface. *Taxodium ascendens* was planted in spaces of 1.5 x 4, 1.2 x 5 or 2 x 3 m, etc. Crops were alternatively inter- or under-planted according to seasons.

Forestry-Fishery-Animal Husbandry -

The types established were "agroforestry-fishery-poultry" and "forestry-sheep-fishery". The poultry were ducks, geese and chicken.

Forestry-Aquatic Crops-Agronomy -

Aquatic crops are special products in this region and most of them are of high value. The width of

Table 1. Biomass and yield of agroforestry system.

Types	I	II	III	IV
Age (yr)	6	4	3	
Stocking volume (m^3/ha/yr)	11.4	7.5	5.7	
Rape yield (kg/ha/yr)	854.7	902.25	1356.00	1329.90
Dry rape weight (g/1,000 grain)	2.54	2.65	2.68	2.72
Tree biomass (t/ha/yr)	9.5	6.25	4.75	
Rape biomass (t/ha/yr)	2.01	2.12	3.19	3.13
Total biomass (t/ha/yr)	11.51	8.37	7.94	3.13

Tree species: *Taxodium ascendens*; intercrop: rape

the shallow pools for planting aquatic crops was 6-25 m and the width of terraces was 2-16 m. Trees were planted on the terraces and crops inter- or under-planted. Aquatic crops were planted in the shallow pools and the major aquatic crops were lotus, arrowhead, wild rice stem and rice.

Forestry-Fishery -
When the canopy became closed and intercrops not used, the forestry-fishery system was established. Two examples are: one is the narrow terrace and wide pond, where raising fish was the major activity. The other was the same as forestry-fishery-agronomy, where forestry was the major component.

Forestry-Edible Fungus -
The research of the forestry-edible fungus system began in 1984, using oyster mushroom (*Pleurotus ostreatus*). The technology for growing oyster mushroom was well developed. There was high profit and organic matter was put onto the forest land for growing mushrooms. The organic matter was good fertiliser.

Management Techniques for Agroforestry Systems

The influence of ecological factors on fisheries was measured from 1985 to 1986, which included oxygen in water, plankton, radiation, water temperature, air temperature, wind speed and humidity. The influence of the stand structure on the oxygen in water, and water temperature was less than that on the plankton and radiation. Other conditions that encourage fish production were determined.

Dynamics of Stands -
The influence of different stocking density on intercropping was determined in 1977. The plantation density of *Taxodium distichum* was 825, 1665 and 3330 trees per ha with spacings of 3 x 4, 3 x 3, 2 x 3 and 1.5 x 2 m. Wheat, rape, etc. were interplanted. The result showed that the canopy was closed from the 6th year after planting in the stand with 3,330 trees per ha. The intercropping of wheat and rape was considerably limited at this time and first thinning was carried out in 1985. The canopy of the stand with 1,665 trees per ha started to close from the 8th year after planting. The increment trend of the dbh of the trees in the stand with 3,330 trees per ha decreased from 5th year, and the annual increment of dbh was 1.5 cm in the 5th year, 1.4 cm/6th, 1.0 cm/7th and 0.8 cm/8th years. The annual increment of dbh in others such as 1,665, 1,110 and 825 trees per ha was 1.88, 2.65 and 3.54 cm respectively when the stands were 8 years old. The proper planting density lengthened the intercropping period and increased the commercial value of wood, productivity of land and economic benefits.

Influence of Canopy Density on Intercropping-
The canopy density of the stands with 1,650 trees per ha, from 3-9 years old was 0.167, 0.238, 0.298, 0.364, 0.437, 0.517 and 0.697 respectively. Rape yields in the stands of *Taxodium ascendens* with 3, 4 and 6 years old were 1356, 902.25 and 854.7 kg/ha, versus the yield in the open fields which was 1,329.9 kg/ha. No influence was observed in 3-year old stands and in stands of 6 years old the rape yield was 35.7% less, seed weight per 1,000 grains was 6.6% less, and the rape biomass was 35.8% less than that in the open field. The total biomass of tree-rape system was 3.68 times high as that of the rape field without trees.

Productivity -
As shown in Table 1, the total biomass of a

tree-crop system was considerably higher than the trees or crops singly planted. Although the products of rape decreased in the stands of 6 and 4 years old, the total output of the tree-rape was far higher than that of the rape in open field, and the difference of the dry rape weight per 1,000 grains was negligible between the types.

Resource Sharing in Ecological Space -

In the integral systems of forestry-fishery-agronomy-water plants, the upper level was trees, the second crops, the third water plants, with lower level fish. The resources of light, nutrients, water, etc. were fully shared in stereo-space. Sequentially, several combinations of crops were alternately planted. They shared the various resource pools in time, horizontal and vertical dimensions. The combinations of intercrops were rape-soybean, rape or wheat-taro, wheat-soybean, rape or wheat-rice, rape or wheat-cotton, rape or wheat-green vegetables, rape or wheat-water melon-Chinese cabbage, rape or wheat-taro-Chinese cabbage.

Ecological Conditions in Agroforestry Systems

The measurements of ecological factors were carried out in the field of forest-rape in 1986. The age of stands was 6 years old which was considered as type I; 4 years old as type II and the rape field in monoculture considered as type III.

Radiation - As compared with type III, the radiation through canopy in the stands of type I decreased 57% at 6 am, 26% at 11 am, 53% at 2 pm, 68% at 6 pm, and the radiation in the stands of type II decreased 33% at 6 am, 19% at 2 pm, 54% at 6 pm. The light through canopy decreased with stand age. The radiation through the canopy of type I, as compared with type II, decreased 36% at 6 am, 49% at 10 am, 41% at 2 pm and 31% at 6 pm. Thus, radiation change was very helpful for determining the intercropping combination of agroforestry system.

Air temperature - The air temperature in type I and type II was 0.7-2.6°C lower than that of type III. The influence of the temperature change among three types on rape was not significant, for *Taxodium ascendens* with a small and thin crown was a deciduous conifer which renewed its foliage in middle April and the rape was harvested in late May.

Soil temperature - The soil temperature of type I and type II was lower than that of type III at 6 am, but the temperature of type I and type II in the 5 cm and 25 cm deep soil from ground surface decreased faster than that of type III at 6 pm.

Humidity - The relative air humidity in type I and type II was higher than that in type III, especially at 2 pm and 6 pm.

Ecological factors were measured in the forestry-fishery-agronomy systems which were established in 1983. The tree species was *Taxodium ascendens* and the spacing was 2 x 3 m.

Radiation - When measured, the influence of radiation through the canopy on fish ponds was insignificant when the stand age was less than 4 years old. At noon, the radiation on the pond was exactly the same as that of open ponds without trees.

Water temperature - The water temperature of the fish pond in the forestry-fishery-agronomy system (FFAS) was 0.7°C lower at 2 pm and 0.1°C lower at 6 pm.

Air temperature - The air temperature of FFAS was 0.1°C lower than that of the open site without trees at 8 am, the same at 2 pm and 0.7°C lower at 6 pm.

Soil temperature - The soil temperature in the terrace of FFAS at 5 cm depth from ground surface was 1.4°C lower than that in the terrace without trees. It was 0.2°C lower at 25 cm depth and 0.7°C lower at 50 cm depth.

Humidity - The relative air humidity of FFAS was 0.7% higher than that of the open site without trees at 8 am, 18% higher at 2 pm and 10% higher at 6 pm.

Economic Benefits and Evaluation

Trees - The stocking volume of agroforestry systems, where the age of the stand varied from 3-9 years old was measured in 1984, 1985 and 1986. The annual increment was 16.5 m/ha/yr with cash value of $2,475/ha/yr ($150 per m according to the current market price).

Crops - The optimum type of intercrops were watermelon-taro-Chinese cabbage where the net profit was $2,331.08/ha/yr, the second, rape-melon type, net profit $1,581.08/ha/yr, the third, rape-taro type, net profit $1,481.92/ha/yr, the fourth, ginger-rape type, net profit $1,216.22/ha/yr, the fifth, barley-cotton type, net profit $912.16/ha/yr, and the sixth, rape-cotton type, net profit $891.89/ha/yr.

Fishery - The fish products of the forestry-fishery-agronomy system was established in 1983, ranged from 2,250-6,225 kg/ha/yr and net profits ranged from $1,127.03-4,277.03/ha/yr.

Aquatic plants - The lotus and arrowhead of the forestry-aquatic plant system was established in 1983, and products were 7.500 and 1,500 kg/ha/yr respectively with net profit $1,621.62/ha/yr.

Edible fungus - The product of the oyster mushroom of the forestry-edible fungus system, which began in 1984, 1985 and 1986 reached a very high level, net profit $3,243.24/ha/yr in 1986. According to economic evaluation models (Huang Baolong and Huang Wending 1986), the total investment was realised within two years. The ratio of output to input in all the types was far more than 1, and ranged from 1.02-7.14, and the ratio of the total net profit to the engineering investment ranged from 15.3-90.7. Nine years after exploitation in the forestry-agronomy, and forestry system were 10-30 times as high as before exploitation, and 1-2 times higher than that of the monocultured crops or trees.

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A Study on *Paulownia*-Tea Intercropping System - Microclimate Modification and Economic Benefits

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ABSTRACT

Intercropping Paulownia with tea in multi-storey ecosystem modifies microclimatic conditions in tea plantations and helps to use limited land available efficiently. The modification of microclimate favours tea growth, improves quality and increases economic returns per unit landuse system.

Introduction

Tea (*Camellia sinesis*) is a light and humid loving, shade tolerant tree species. The light utilisation efficiency of a pure cultured tea planation is very low due to its low light saturation point. The growth and quality of tea is negatively affected by strong light, high temperature and low humidity. During the last two decades, most tea producing countries such as India, Japan, and Soviet Union have been focusing on the study of ecophysiological conditions, processing method and tea quality. Tea is usually grown under the shading of trees. Chinese people started to interplant trees with tea from Shong Dynasty (D.C. 960-1,279), which was further developed after 1953. Intercropping trees like pear, Mason pine and walnut was concluded as undesirable during 1950-1960s. *Hevea brasiliensis*-tea intercropping was first practised in Puwen, Yunnan Province in 1959. Tea-grapes, tea intercropping with other fruit trees was also successful between 1970 and 1985 (Wang, 1987). The microclimate modifications and economic benefits from the intercropping of *Paulownia* in tea plantations is discussed in this paper.

Materials and Methods

Materials -
Paulownia fortunei was selected as the intercropping tree species which is a fast-growing species. It is an indigenous and dominant species in China growing in tropical and subtropical conditions. The timber is a main export item of China.

Site Description -
The experimental plots were located in Maodong Forest Farm, Jintan County of Jiangsu Province (termed Site A) and Tonglin *Paulownia* Research Station in Anhui Province (called Site B). The experimental design for the study was shown in Table 1. The planting spacings of tea plants were 0.3 x 1.5 and 0.5 x 2 m respectively in Sites A and B. Tea plantations without *Paulownia* served as control.

Data Collection -
The diameter and height growth of *Paulownia* were measured once a year and the timber volume accumulation was estimated every two years from the date of planting. In Site B, the number of buds and young leaves were counted in spring. In Site A, 1 m^2 sample plots were set to record data of tea yield at the time of harvest. The distribution of root system of the intercropping system was investigated in 1988 in both Sites A and B; microclimate data (including wind velocity, radiation, temperature, humidity) were collected using a CE-256 automatic weather equipment. Tea leaves' temperature, transpiration and diffusion resistance were measured using L1-1006 state porometer, and photosynthesis was measured using CH-111 photosynthesis meter. A gravimetric (oven-dry) method was adopted for measuring water content

Table 1. Experimental design layout

Site	Block	Tree age (yr)	Treatments		
			Spacings (m)	Shading rate (%)	Code name
A	I	8	10 x 10	37.7	AI-1
			5 x 7	100.0	AI-2
			Control		AI-3
	II	6	5 x 10	51	AII-1
			6 x 8	53	AII-2
			Control		AII-3
B	I	10	5 x 10	60.1	BI-1
			Control		BI-2
	II	8	6 x 12	66.9	BII-1
			Control		BII-2

Table 2. Microclimate modification in Paulownia-tea intercropping (1)

Treatments	Intercropping plot				Control plot				Reduction (%)			
	RA (J/s)	WV (m/s)	TEM (°C)	HUM (%)	RA (J/s)	WV (m/s)	TEM (°C)	HUM (%)	RA	WV	TEM	HUM
AI - 1	48.07	1.11	22.70		73.64	1.93	23.00		-34.7	-42.5	-1.3	
AI - 2	38.17	0.56	24.91		118.5	1.04	25.17		-67.8	-46.2	-1.03	
AII - 1	37.51	0.47	24.66	79	95.85	0.60	26.15	69	-60.9	-21.5	-5.7	-14.5

RA - Radiation; WV - Wind velocity; TEM - Temperature; HUM - Humidity.
(Data collected from 14-17 July 1987)

of the tea leaves. The chemical analysis was done of samples with one bud and two leaves. Through steam fixation, vitamin C content was obtained using the super liquid chromatogram method. Eighteen amino acids were measured using an automatic water amino acids analysis instrument. A UV-190 photoelectric colorimeter was used for chemical analysis.

Results and Discussion

Microclimate Modification under the Shading of *Paulownia* -

Radiation: The radiation reaching the tea plants was obviously reduced during summer under the shading of *Paulownia* canopies. Its reduction depended on the density of canopies. Observations in Site A during 14-17 July 1987 showed that the radiation decreased by 67.8% and 34.7% respectively in *Paulownia* spacings of 5 x 7 and 10 x 10 m as compared to the control. Similar results were obtained from Site B (Table 2, Fig. 1). The reduced radiation was favourable for the growth of tea plants, however, negative effect to tea's growth was observed in the over shading plantations. Thirty-seven percent of shading (tree planting spacing of 10 x 10 m) was considered the optimum, while 100% shading (spacing of 5 x 7 m) affected growth and quality of tea and reduced tea yield, this was termed hard shading; 51-53% shading (spacings of 5 x 10 and 6 x 8 m) negatively affected tea growth, this was listed as over-shading.

Wind Velocity: Wind velocity was greatly reduced and wind structure changed in the intercropped system due to the barrier effects of *Paulownia* trees (Fig. 2). Vertical turbulence and air exchange were minimised as a result of wind reduction which was the function of intercropped *Paulownia* density. Denser the spacing, greater was the wind reduction. It was observed in Site A during July to August 1987, and again in 1988 that wind velocities were reduced 42.5-50% and 46.2-66.2% respectively. In *Paulownia* spacings of 10 x 10 and 5 x 7 m, the reduction range of the former was 8.7-24.5% higher than the latter (Tables 2 and 3).

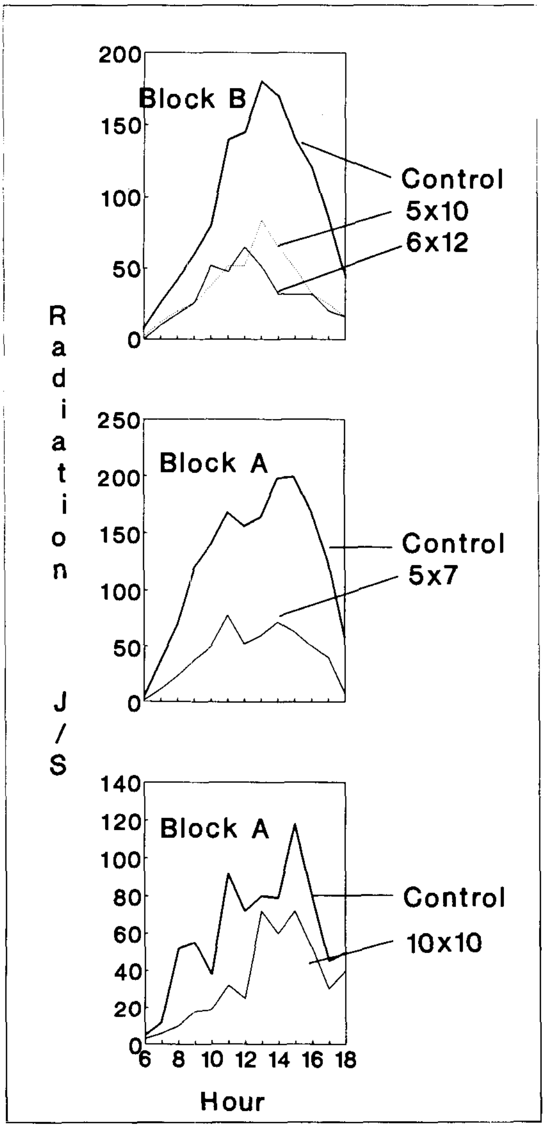

Fig. 1 *Daily variation of radiation under different shade condition*

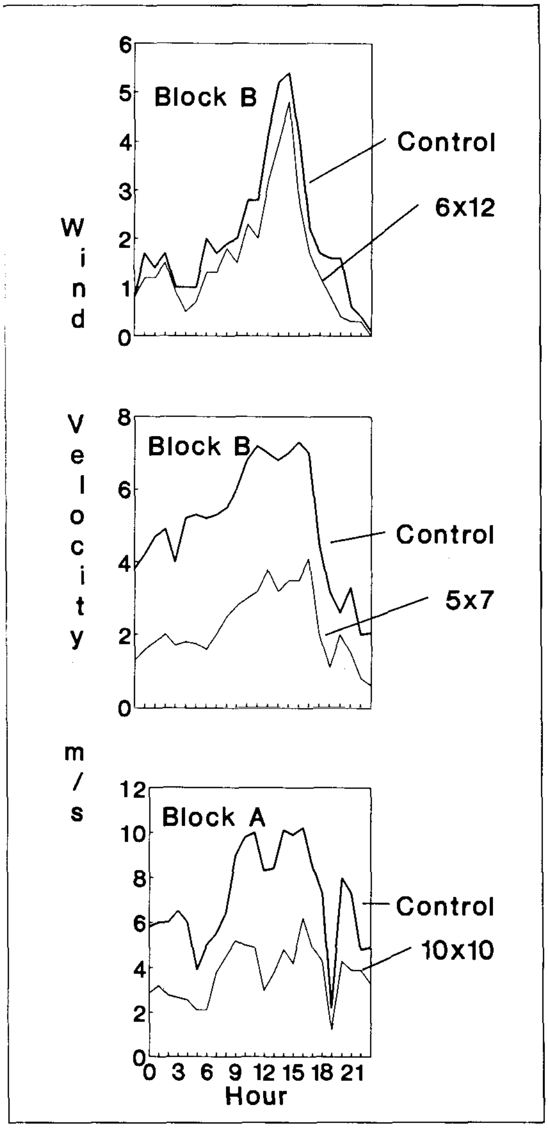

Fig. 2 *Daily variation of wind velocity under different shade conditions*

Air Temperature: Temperature under *Paulownia* shading was lower compared to open fields and it decreased according to the reduction of wind velocity and radiation (Tables 2 and 3; Fig. 3). Temperature vertical variation between 0.2-1.5 m from soil surface was greater in intercropping than in control (Table 4). Maximum temperature was lower than in control. Its reduction was varied with height (Table 4). Temperature amplitude at different heights averaged 5°C in intercropping and 7.3°C in control fields. In intercropping fields, tea canopy layer temperature was 37°C, at 1.5 m height, while the tea canopy temperature reached 41.5°C at the height of 1.5 m in the control fields. Under the high temperature new tea sprouts appeared to wilt.

Soil Temperature: Soil temperature decreased in intercropping systems because of the reduction of radiation. Its decrease was greater in shallow layers than in deep layers, therefor the higher the shading, the greater the reduction degree. Investigation in Sites A and B during July 1987 to August 1988 indicated that soil temperature at 5-20 cm under the soil surface in intercropping was apparently lower than that in control. The average temperature amplitude was 0.8-1.7°C, 3.1-4.6 times lower in intercropping than that in control. Difference between maximum and minimum was

Table 3. Microclimate modification in Paulownia-tea intercropping (2)

Treatments	WV (m/s)	TEM (^oC)	RH (%)	EV (mm)	Reduction (%)			
					WV	TEM	RH	EV
AI - 1	1.1	27.0	86.1	2.6	-50.0	-0.4	+1.5	-36.6
AI - 2	0.74	27.0	90.6	2.4	-60.4	-0.4	+6.8	-41.5
AI - 3	2.2	27.0	84.8	4.1				

Table 4. Air temperature at different heights of intercropping system and comparison with controls

Observation height (cm)	Treatments	Maximum temperature (^oC)	Minimum temperature (^oC)	Max. - Min. (^oC)	Absolute Temperature (^oC)
20	Intercrop	30.9	26.0	4.9	36.5
	Control	33.4	26.0	7.4	39.5
50	Intercrop	31.9	26.8	5.1	36.8
	Control	34.0	26.8	7.2	39.0
150	Intercrop	32.6	28.2	4.4	37.0
	Control	33.6	28.2	5.4	37.5
Tea canopy	Intercrop	31.9	26.4	5.5	37.0
	Control	35.3	26.1	9.2	41.5

Table 5. Daily variation of soil temperature at different depths in intercropping plots and comparison with the control plots

Observation time			9:00	11:00	13:00	15:00	17:00	Means	Amplitude
Site A	Inter-cropping	5 cm	23.0	23.4	24.5	25.0	25.5	24.28	2.5
		10 cm	22.5	23.0	23.6	24.3	24.6	23.60	2.1
		15 cm	22.5	22.6	23.2	23.5	23.7	23.10	1.2
		20 cm	22.5	22.5	22.9	23.4	23.5	22.96	1.0
		Means	22.60	22.80	23.55	24.05	24.32	23.49	1.7
		Diff.	0.5	0.9	1.6	1.6	2.0	1.32	
	Control	5 cm	25.5	31.5	35.3	36.5	31.2	32.00	11.0
		10 cm	23.0	26.9	30.5	32.0	30.9	28.66	9.0
		15 cm	22.0	24.1	27.0	28.4	29.0	26.10	7.0
		20 cm	22.0	23.5	25.5	26.6	27.6	25.04	5.6
		Means	23.12	28.25	29.58	30.88	29.68	27.95	8.15
		Diff.	3.5	9.5	9.8	9.9	3.6	7.26	
Site B	Inter-cropping	5 cm	24.2	24.5	25.0	25.4	25.9	25.00	1.7
		10 cm	23.7	23.8	24.1	24.4	24.6	24.12	0.9
		15 cm	23.9	23.8	23.9	24.1	24.3	24.00	0.4
		20 cm	23.9	23.8	23.8	24.0	24.1	23.92	0.3
		Means	23.92	24.00	24.20	24.47	24.13	24.26	0.83
		Diff.	0.5	0.7	1.2	1.4	1.8	1.12	
	Control	5 cm	25.0	26.2	27.8	28.9	30.2	27.62	5.1
		10 cm	25.1	25.4	26.3	27.1	27.9	26.36	2.8
		15 cm	24.6	24.6	25.1	25.5	26.1	25.18	1.5
		20 cm	24.8	24.9	24.9	25.0	25.2	24.96	0.4
		Means	24.88	25.28	26.03	26.63	27.35	26.03	2.45
		Diff.	0.5	1.6	2.9	3.9	5.0	2.78	

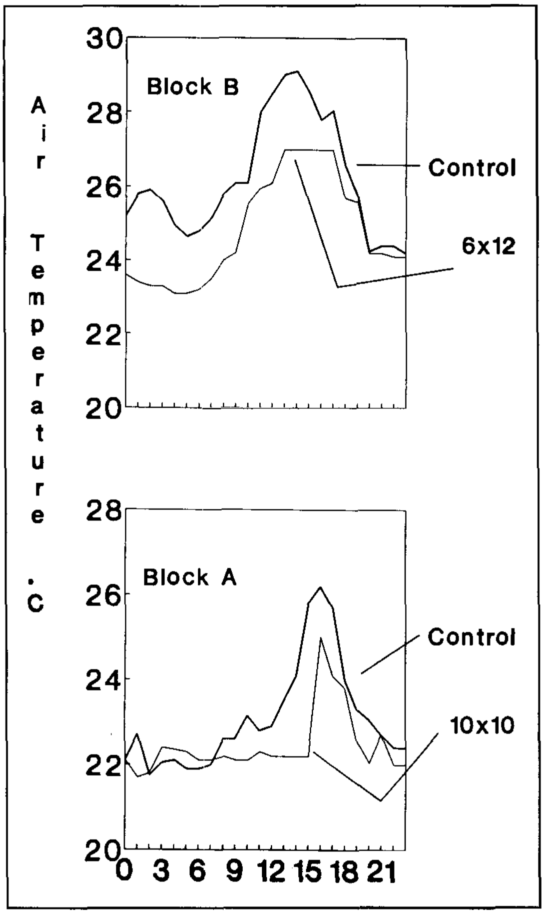

Fig. 3 Daily temperature variation under different shade conditions

1.1-1.38°C in intercropping and 2.75-6.77°C in control (Table 5). The general trends are: difference is greater in the evening and smaller in the morning; the nearer it is to the ground surface, the greater is the difference. Soil temperature reduction was also related to shading degree and the time of day. Table 6 shows that temperature was lower in over-shading areas compared with optimum shading. The effect of shading on temperature was much different before 9 am and it became greater with the increase of radiation in afternoon. Soil temperature was less in intercropping as compared to control. In summary, air and soil temperature was reduced in *Paulownia*-tea intercropping due to the affect of tree canopy shading and tea damage was prevented in summer by shading.

Humidity and Evaporation: Humidity increased and evaporation decreased in intercropping because of the reduction of wind velocity and radiation. The variation of humidity and evaporation depended on the density of *Paulownia* and the time of day. Humidity differences between intercropping and control were greater in fine weather and in the afternoons, and lower at night in cold weather. The denser the canopies, the higher was the humidity and evaporation decreased with reduction of humidity. Relative humidity increased by 1.5% and evaporation decreased by 36.6% in suitable shading as compared to the control (Table 3, Fig.4).

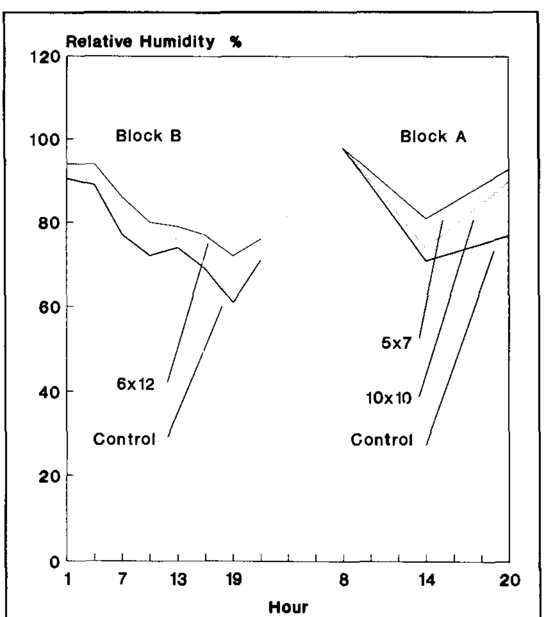

Fig. 4 Daily relative humidity variation under different shade conditions

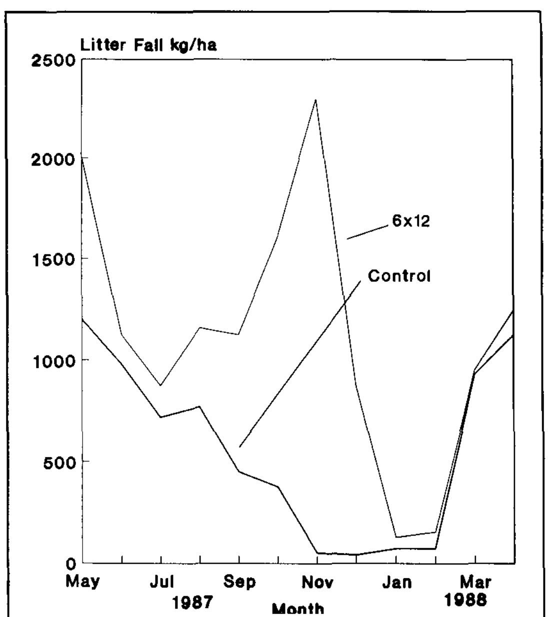

Fig. 5 Litter fall variation of intercropped plots and control plots

Table 6. Soil temperature under different shading conditions

Treatments	Intercropping (°C)				Control (°C)				Reduction (%)			
	5 cm	10 cm	15 cm	20 cm	5 cm	10 cm	15 cm	20 cm	5 cm	10 cm	15 cm	20 cm
AI - 1	28.50	27.20	25.50	26.00	31.10	29.50	27.80	26.90	8.4	7.8	8.3	3.3
AI - 2	24.39	23.71	23.21	23.01	32.07	28.85	26.37	25.30	23.9	17.8	12.0	9.1
BII - 1	25.01	24.12	24.01	23.94	27.61	26.36	25.18	24.95	9.4	8.5	4.6	4.0

All the data are daily means and observed in July 14-17, 1987

Table 7. Nutrient content comparison between intercropping and control plots

Tr.	Intercropping				Control			
Po.	20	50	100	Mean	20	50	100	Mean
N	190	158	105	151	125	103	72	100
P	0.7	0.7	0.7	0.7	0.7	-	-	0.23
K	138	110	82	110	74	70	56	66.7
WC	16.7	15.8	13.9	15.5	4	3.9	2.9	3.6
Ph	4.49	4.12	4.42		4.65	4.70	4.59	

Tr. - Treatment; Po. - Position (distance to tea root in cm); N, P, K - Available N, P, K, in mg/100 g; WC - Water content in %. Soil samples were collected from the top soil (0-4 cm in depth)

Table 8. Effects of shading on transpiration, diffusion resistance and leaf temperature

Treatments	TR $ug/cm^2.s$	DR s/cm	LT °C	Over control (%)		
				Tr.	DR	LT
AI - 1	11.55	5.16	29.73	- 2.4	-7.4	-1.7
AI - 2	9.46	7.65	29.53	-20.0	+37.4	-2.3
AI - 3	11.83	5.57	30.24			

TR - Transpiration; DR - Diffusion resistance; LT - Leaf temperature

Table 9. Effects of intercropping on water contents of fresh tea leaves

Treatment	Date/Season of test	Water content (%)	Higher than Control (%)
AI - 1	April 29	76.2	0.7
AI - 2	spring	76.1	0.7
AI - 3		75.6	
AII - 1	June 17	78.05	1.76
AII - 2	Summer	76.1	2.09
AII - 3		75.6	
AI - 1	Sep. 21	79.6	4.5
AI - 2	Fall	79.6	4.5
AI - 3		76.1	
AII - 1	Sep. 21	72.2	12.3
AII - 2	Fall	70.9	10.3
AII - 3		64.3	
BI - 1	May 24	77.6	2.9
BI - 2	Spring	75.4	2.1
BII - 1		74.8	
BII - 2		73.2	

Table 10. Comparison of main chemical element contents between intercropped plots and control plots.

Date/Season of test	Treatment	Phenolic %	Amino acid %	Caffeine %	Sugar %	IS %	Vitamin C	P/A
April 29	AI - 1	18.59	3.33	3.54	13.60	36.17	172	5.58
	AI - 2	18.65	3.16	3.49	13.33	35.17	172	5.90
Spring	AI - 3	20.02	3.23	3.47	13.83	35.17	161.5	6.20
June 17	AI - 1	24.85	1.03	3.89	19.67	38.50	167	24.22
	AI - 2	26.67	0.94	2.77	22.57	38.67	160	28.37
Summer	AI - 3	25.01	0.94	2.78	18.67	37.92	154	22.61
Sep. 21	AI - 1	30.33	0.99	3.00	17.23	38.83		30.70
	AI - 2	29.15	0.98	2.89	16.50	37.50		29.81
Fall	AI - 3	30.49	0.98	2.85	17.08	38.20		31.18
May 20	AII - 2	20.10	2.44	3.28	15.33	37.96		8.23
Spring	AII - 3	20.02	2.47	3.20	15.74	38.75		8.11
July 17	AII - 2	25.00	0.78	2.80	19.58	39.54		32.20
Summer	AII - 3	24.06	0.91	2.69	18.38	39.17		26.50
Sep. 21	AII - 2	30.77	0.72	2.95	17.58	39.38		42.90
Fall	AII - 3	30.26	0.69	3.07	18.17	39.59		43.90
May 24	BI - 1	24.06	1.79	3.17	17.77	41.50		13.44
	BI - 2	23.15	1.82	3.07	16.73	41.67		12.72
Spring	BII - 1	27.52	1.57	3.47	18.90	44.08		17.53
	BII - 2	25.83	1.68	3.15	18.84	43.58		15.38
Summer	BI - 1	24.35	1.00	3.48	16.42	38.42		24.55
	BI - 2	25.66	0.77	2.57	17.18	40.09		33.53
	BII - 1	45.37	1.02	3.46	16.53	39.67		24.87
	BII - 2	25.37	0.98	3.28	17.53	39.94		25.89

IS - Immersed substance; P/A - Phenolic/Amino acid

Soil Nutrient Contents -

Paulownia leaves, flowers, fruits and pruned tea branches and leaves were returned to the soil in large amounts. Litter return was higher in intercropping than in control which only received the litter from pruning and left leaves of tea plants during March-June (Fig. 5). With aging, *Paulownia* crown became very large and the litter fall was greater. Decomposed year by year, humus contents were consequently ameliorated and fertilised the soil (Table 7). It was observed that N, P, K contents of top soil (up to 4 cm in depth) increased 51%, 204% and 64% respectively in intercropping than in control.

Physiological Changes in Tea Buds and Leaves Under Shading of *Paulownia* -

Photosynthesis: Daily variations of photosynthesis depended on environmental factors. Figure 6 shows that in control fields, the photosynthesis had its first peak with an intensity of 10.54 mg CO_2/cm.h at 11:30 am. Then the curve falls with the increase of solar radiation and air temperature until it reaches the valley, i.e., minimum point with the intensity of 2.88 mg CO_2/cm.h, termed the "noon rest". The second peak appeared at 14:30 pm with the intensity of 13.15 mg CO_2/cm.h. There was only a single peak in intercropping fields, and the peak value was higher than that of the control. In terms of daily average value, the intensities were 7.54, 7.07 and 6.59 mg CO_2/cm.h respectively, in suitable shading, control and hard shading fields.

Transpiration, diffusion resistance and leaf temperature - Water absorbed from soil by roots was mostly lost through transpiration. The pores were resistant to water vapour transpiration. Transpiration varied negatively varied with diffusion resistance and negatively affected leaf

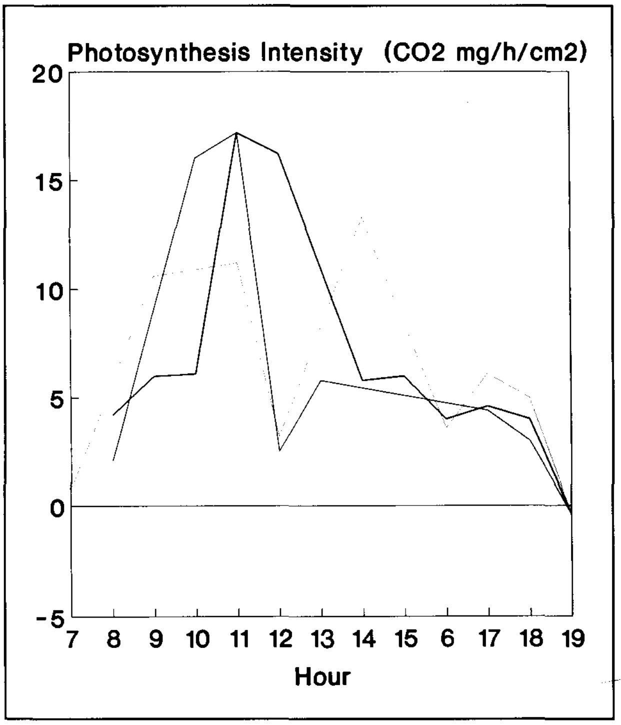

Fig. 6 Effects of shading on the photosynthesis of tea plants

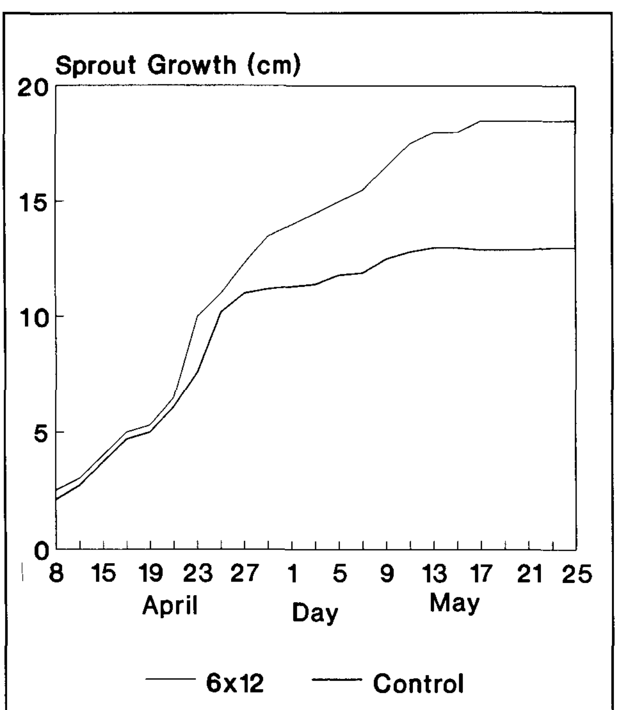

Fig. 8 Effects of shading on tea sprout growth increments

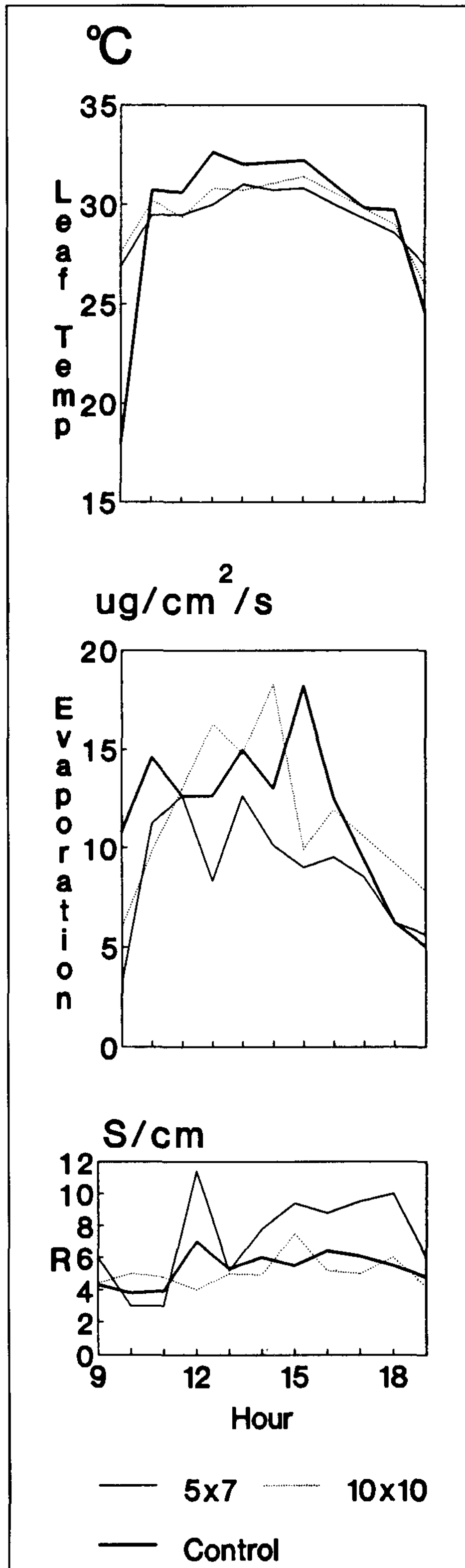

Fig. 7 Daily variations of transpiration, diffusion resistence and leaf temperature

Table 11. Comparison of amino acid contents between intercropping plots.

Amino acid	Spring tea			Summer tea		
	AI - 3	AI - 1	AI - 2	AI - 3	AI - 1	AI - 2
ASP	172.5	182.0	183.0	65.9	70.5	67.1
THR	60.3	67.2	60.0	23.2	22.7	22.2
SER	81.6	92.4	84.0	28.7	30.2	29.9
GLU	335.1	358.4	363.0	128.3	137.3	132.1
PRO	13.5	14.0	21.0	5.7	7.6	5.6
GLY	13.2	16.8	9.0	4.0	3.7	3.3
ALA	36.0	42.0	33.0	11.3	12.6	11.1
CYS	32.4	33.6	30.0	12.5	13.8	11.1
VAL	9.3	11.2	9.0	3.4	3.8	3.3
MET	8.1	8.4	9.0	4.5	5.0	4.4
ILE	19.2	30.8	12.0	4.5	5.0	4.4
LEU	16.2	16.8	18.0	6.8	7.4	6.6
TYR	67.2	44.8	99.0	35.0	39.1	34.1
PHE	49.5	56.0	51.0	19.8	22.6	18.7
HIS	45.6	50.4	45.0	17.0	20.2	16.6
TAA*	1530.0	1602.0	1584.0	564.0	615.6	564.0
LYS	13.5	14.0	15.0	3.4	6.3	4.4
ARG	2.15	2.2	2.2	1.0	1.1	1.0

TEA - Tea amino acid.

temperature. These physiological activities were controlled by the microclimate and other environmental factors. Table 8 and Fig. 7 show that the trends of the three physiological processes varied under different shading conditions.

Water content of buds and leaves - Water is an essential substance for physiological activities. Abundant water activates the physiological process, and forces the accumulation of protein and caffeine which are the signs of tenderness and quality of tea. Increased humidity and soil moisture are effective measures to raise tea moisture. Measurement results at Site A during 1987 are listed in Table 9 which indicates that the average tea water content was 0.7-12.3% higher in intercropped area than in control.

Chemical Component Changes in Tea Leaves Under Shading of *Paulownia*: Chemical contents were closely related to shading and suitable shading improved tea quality. Analysed results in spring, summer and fall in Site A during 1987 showed that amino acids, caffeine and vitamin C increased under suitable shading, and phenolic content of tea and ratio of phenolic over amino acids were lower under suitable shading than that in the control for spring and fall tea (Table 10). The phenolic content of summer tea increased under hard shading. There are more than 25 types of amino acids in tea leaves and the contents of 18 of these amino acids in tea were measured (Table 11). Results showed that the tea amino acid, GLU and ASP contents were the highest; tea amino acid/ accounted for 50% of the total contents of the 18 amino acids. Under the suitable shading condition, the contents of most amino acids increased. In contrast, the contents of amino acids decreased under the hard shading condition.

Effects of *Paulownia* Shading on the Yield of New Sprouts and Fresh Leaves -

The modification of microclimate under shading conditions affected the development of new tea sprouts. The earliest time for sprouts prolongation in intercropping plantation was March 21, while in the control plots it was not until March 26.

Shading promotes early emergence of sprouts. Hard shading reduced the bud number so the yield and quality directly effected the ratio of terminal leaf number over axillary leaf number. The lower the axillary leaf number, better was the tea quality. Table 12 indicates that axillary leaves in suitable, hard shading and control were 54.6%, 63.7% and 58.9% respectively. There were similar trends in the length of vegetative growth (Table 13, Fig. 8).

Economic Benefits -

The tea yield was affected by modification of the microclimate. Sample plot data were fixed and

Table 12. Sprout number comparison of spring tea among intercropped and control plots.

Date of collection	Treatment	Total number counted	OWT No.	OWT %	PAL No.	PAL %
May 1	AI - 1	226	124	54.9	102	45.1
	AI - 2	221	108	48.9	113	51.1
	AI - 3	237	135	57.0	102	43.0
May 10	AI - 1	231	94	40.7	137	59.3
	AI - 2	200	61	30.5	139	69.5
	AI - 3	216	71	32.9	145	67.1
May 20	AI - 1	133	49	36.8	84	63.2
	AI - 2	91	17	18.7	74	81.3
	AI - 3	114	27	23.7	87	76.3
Average	AI - 1	196.7	89	45.2	107.7	54.6
	AI - 2	107.7	62	36.3	108.7	63.7
	AI - 3	189	77.7	41.1	111.3	58.9

OWT - One bud with two leaves.
PAL - Pair of axillary leaves.

Table 13. Comparison of tea sprouts in intercropped plants and control.

Treatments	Bud length	Leaf length One leaf	Leaf length Two leaves	Leaf width One leaf	Leaf width Two leaves	Hundred buds weight Fresh (g)	Hundred buds weight Air Dry(g)	Hundred buds weight Dry/ Fresh	Node length
BII-1	2.27	3.5	4.71	1.3	1.97	31.5	7.5	23.8	2.65
BII-2	1.5	2.54	3.3	0.96	1.59	17.5	4.5	25.7	2.45
BI-1	1.9	3.34	4.82	1.22	1.97	37.5	9.8	26.1	2.47
BI-2	1.65	2.93	4.41	1.02	1.68	25.0	7.7	30.8	2.39

All the data are the means of 50 samples.

collected during the harvest season (spring, summer and fall). The sample plot was 1 m with three replications. The results showed that suitable shading increased tea quality, leaf number and weight per leaf. Bud and leaf numbers increased 1.8-9.6%, per leaf weight increased 2-5.8%, consequently tea yield increased by 14.4%, 7%, 7.9% and 10.2 respectively for spring, summer, fall tea and per year in suitable shading over that of the control. In contrast, hard shading had a negative effect on tea yield and leaf number per unit area due to radiation reduction. Bud and leaf number were reduced 30-41.9%, but single leaf weight increased 10.3-34.1% under hard shading. Due to the great reduction in leaf number, spring, summer, fall and total tea yields decreased by 16.3%, 23.2%, 45.6% and 26.8% respectively (Table 14). ANOVA shows that there were no significant differences among tea yields under optimum conditions, over shading and control. However, tea yields in suitable shading and control were apparently higher than that under hard shading (Table 15).

Effect of Shading on Flowering and Fruit Bearing -

Tea flowers during August to October when *Paulownia* was vigorously growing, demanding strong light. Under shading conditions, direct light radiation was reduced and the indirect light relatively increased that favoured the formation of N compounds and decreased C/N which was good for vegetative growth. Flowers and fruits in Site B were 75.3% lower under shade than in the control (Table 16).

Table 14. Effect of Paulownia shading on tea yield

Treat-ments	g/m²				Bud number/m²				g/single bud			
	Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
AI - 1	397.5	307.1	268.9	973.5	1764	2038.2	2464.2	6266.4	0.225	0.151	0.109	0.162
AI - 2	290.7	220.3	135.4	646.4	999.2	1355.4	1406.4	3761	0.291	0.163	0.096	0.183
AI - 3	347.4	286.9	249.1	883.4	1600	1936	2420.4	5956.4	0.217	0.148	0.103	0.156

Table 15. ANOVA multiple range test of fresh tea yield under different shading conditions

Treat-ments	Spring tea			Summer tea			Fall tea			Annual total			Over control (%)
	Means	Homogeneous group		Means	Homogeneous group		Means	Homogeneous group		Means	Homogeneous group		
		5%	1%		5%	1%		5%	1%		5%	1%	
AI - 1	397.5	*	*	307.1	*	*	268.9	*	*	973.5	*	*	108.1
AI - 2	290.7	*	*	220.3	*	*	135.4	*	*	646.4	*	*	71.8
AI - 3	364.4	*	*	286.9	*	*	249.1	*	*	900.4	*	*	100
AII - 1	354.9	*	*	317.5	*	*	185.1	*	*	857.5	*	*	92.4
AII - 2	369.9	*	*	337.1	*	*	238.9	*	*	945.9	*	*	101.9
AII - 3	336.9	*	*	349.1	*	*	242.5	*	*	928.5	*	*	100

Table 16. Fruit bearing comparison between intercropping and control

Treat-ments	Number of fruits				
	I	II	III	Mean	Reduc-tion
BI - 1	22	16	15	17.7	-75.7
BI - 2	65	40	113	72.7	

Root Distribution of Intercropping System -

Both *Paulownia* and tea are deep rooted species. However, the distribution of roots were different in the intercropping system since one is a tree and the other a shrub (Tables 17 and 18). The root system of *Paulownia* was mainly located below 40 cm from the soil surface, while the dense root distribution range of tea plants was in 8.3-24.5 cm from the soil surface. So there was not much competition for nutrients and water between the two species.

Growth of *Paulownia* in the Intercropping System -

Beside the function of modification of microclimate and improvement of tea production and quality, *Paulownia* also provided timber. Measurements showed that 8-year old *Paulownia* with spacing of 10 x 10 m reached 10 m in height with a diameter of 28.2 cm, and volume of 26.85 m^3/ha. Growth of 6-year old *Paulownia* with spacings 6 x 8 and 5 x 10 m was an average height of 9.4 m, diameter of 16.9-17.8 cm, single tree volume of 0.084-0.094 m^3 and stocking volume of 16.8-19.65 m^3/ha. *Paulownia* growth improved due to careful management of the tea plantation. Table 19 indicates that *Paulownia* growth was greater in intercropping than on a pure *Paulownia* plantation.

Economic Returns -

Based on the price of 1.2 Chinese Yuan (RMB)/kg, 0.6 Chinese Yuan (RMB)/kg respectively for spring and summer tea, the lowest price 400 Chinese Yuan (RMB)/m^3 was received. The economic returns for different intercropping densities were calculated as shown in Table 20.

Conclusion

Paulownia-tea intercropping was very successful, from which both ecological and economic benefits can be achieved. In order to take full advantage of the new system, the following should be carefully considered. The species for shading should be properly selected. The selected species must have the characteristics of high trunk, narrow crown and sparse branches. The improved planting stocks such as the clones or hybrids of *Paulownia elongata* are promising varieties for the new farming system. The experiments demonstrated that under the same shading degree, high trunk provided tea plants with a favourable modified microclimate. Timely interval of cutting and pruning was done to maintain suitable density with aging of *Paulownia* and to keep high trunk.

According to the biological characteristics of

Table 17. Root distribution of *Paulownia*-tea intercropping system (Site A) (Unit: cm)

Species	Top roots		Absorbing roots		First lateral roots			Second lateral roots		
	No.	Diameter	Dense layer	Deepest layer	No.	Diameter	Total length	No.	Diameter	Total length
Paulownia			40-90	100	7	7.5	654	5	2.9	350
Tea	42	1.5	8.3 - 24.5	33	155	0.6	2894			

Measured in 1/2 Paulownia canopy shading (4 m^2) and the second lateral roots of tea not counted because it is too small to measure

Tabel 18. Distribution of absorbing roots in *Paulownia*-tea intercropping system

Depth (cm)	*Paulownia*		Tea	
	No.	%	No.	%
0 - 20	10.6	2.0	26.7	22.5
20 - 40	63.1	12.0	78.6	65.8
40 - 60	287.6	54.4	14.0	11.7
60 - 80	105.6	20.0		
80 - 100	50.3	9.5		
100 - 120	11.1	2.1		

Table 19. Volume accumulation of 7-year old *Paulownia* in different planting systems

Forest type	Intercropping			Pure planting
Spacing (trees/ha)	135	135	195	330
Volume per trees (m^2)	0.1636	0.2312	0.2022	0.13108
Volume per ha (m^2)	22.091	31.212	39.195	43.258

Table 20. Comparison of economic yields, output value of different planting systems. (Unit: Chinese Yuan [RMB])

Age (yr)	Treat-ments	*Paulownia*		Fresh tea								Total Aann. Output Value	Over Control (%)
		m^3/ha	Annual output value	Spring tea		Summer tea		Fall tea		Annual total			
				kg	Value	kg	Value	kg	Value	kg	Value		
8	AI - 1	26.85	1342.5	3180	3816	2555.3	1533.2	2151.8	1291.1	7887.1	6640.3	7882.8	31.5
	AI - 2	50.7	2535	2321.2	2785.2	1762.5	1057.5	1083	649.8	5166.5	4492.5	7027.5	15.7
	AI - 3			2915.3	3498.4	2296.5	1377.9	1992.8	1195.7	7204.6	6072	6072	0
6	AII - 1	16.8	1120.5	2985	3582	2697	1618.2	1707	1024.2	7389	6224.4	7344.9	20.2
	AII - 2	19.65	1309.5	2841	3409.2	2541	1524.6	1386.8	832.1	6768.8	5765.9	7075.4	15.8
	AII - 3			2969.3	3235.6	2793	1675.8	2000.3	1200.2	7489.6	6111.6	6111.6	0

Paulownia and tea, fertile and deep soil site conditions should be selected for the establishment of the new farming system. The ecological effects of the farming system mainly depended on the shading degree. *Paulownia* planting spacing of 10 x 10 m yielded a shading degree of 37%. This was the best of all the tested spacings. In order to maintain suitable shading conditions for the growth of tea, thinning and other management means should be conducted.

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Physiological and Biochemical Characteristics of Tea Plants Interplanted with Trees

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ABSTRACT

This paper deals with the growing characteristics and physiological and biochemical changes of tea plants under conditions of intercropping with trees. According to several years experiments, tea growth comparison between interplanting and pure planting systems, and the physiological and biochemical changes of tea plants under different shading conditions are presented in this paper. An integrated evaluation of tea-forest interplanting is summarised.
Key Words *Tea plant; interplanting; physiological and biochemical characteristics*

Introduction

Tea plants (*Camellia sinensis*), which originated in China, are typical plants of the subtropical zone. China has a history of 3,000 years of tea cultivation (CAAS, 1986). As far back as the 7th century, China recorded tea plants interplanted with food crops. In the 10th century, Fujian Province recorded tea plants interplanted with tong oil tree (*Aleurites fordii*). The question of shading tea plantations has long been a source of controversy. Early reports (Buckingham, 1885) stated that leguminous trees such as *Albizzia chinensis* were beneficial to promote the quality and yield of tea, but the research results of Mccalloch, Shaxson and Kerfoot showed a decrease of tea yield. All the shade experiments conducted in different site conditions with various species did not give beneficial results or drawbacks of shading. In this paper, the growing characteristics and physiological and biochemical changes of tea plants shaded under forests in China will be analysed.

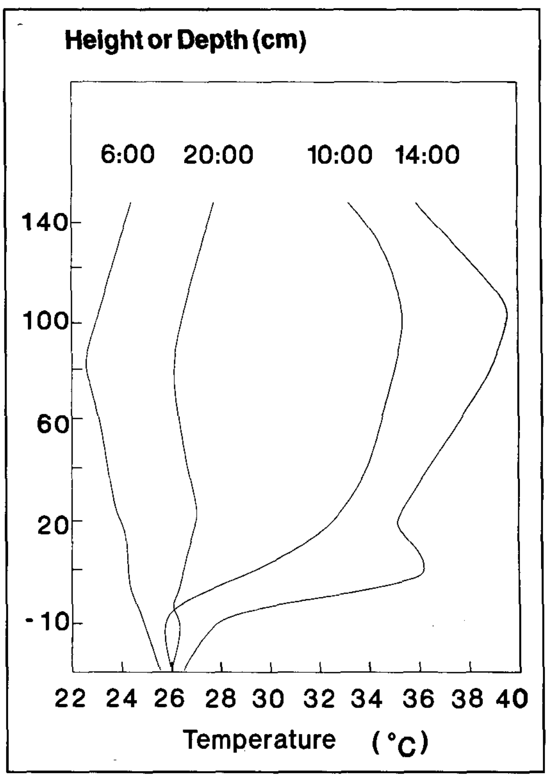

Fig. 1 *Daily variation of soil and air temperature in tea-tree interplanting system (Yuhan of Zhejiang Province, data observed in August 10-11, 1979)*

General Description of Tea Intercropping in China

To the present, there have been 0.1 million ha of tea plants intercropped under forests in China about 10% of the total area of tea plantations. The

Table 1. The influence of shading on leaf anatomical structure of tea plants.

Tea varieties	Longjing			Fuding		
Shading percentage	90	50	0	75	50	0
Thickness of whole leaf (%m)	148.5	166.3	273.3	215.0	263.8	295.5
Thickness of upper cuticular layer (%m)	14.9	17.8	23.8	19.5	22.8	26.0
Thickness of lower epidermis and cuticular layer (%m)	11.9	11.9	17.8	19.6	13.0	19.5
Layer number of palisade tissue	1	2	3	1	2	3
Thickness of palisade tissue (%m)	44.6	59.4	107.9	59.0	94.0	110.0
Thickness of spongy tissue (%m)	77.2	77.2	126.7	117.0	133.0	140.0
Ratio of palisade tissue to spongy tissue (%)	59	75	85	52	84	79

Table 2. The influence of shading condition on respiratory intensity (dry matter mg/dm.hr) and transpiration intensity (g/m.hr) of Fuding tea.

Item	Date	Shading degree (%)			
		75	50	30	0
Respiratory intensity	May 2	4.7	5.3	5.4	6.7
	Jun 5	-	8.7	16.2	26.0
	Sep 9	-	8.2	15.9	63.6
Transpiration intensity	Jun 5	327.3	480.0	464.5	505.6
	Jul 2	206.3	232.3	265.7	272.6
	Aug 4	-	525.2	534.3	544.9
	Sep 9	258.3	364.4	434.6	452.6

method of interplanting and the associated tree species include: strawberry tree (*Myrica*), citrus tree (*Citrus unshiu*), Laquat (*Eriobotrya*), peach (*Prunus persica*), plums (*Prunus spp*.), Persimmon (*Diospyros*), pear (*Pyrus*), grape (*Vitis* spp.), Chinese sapium (*Sapium sebiferum*), Tung oil tree (*Aleurites fordii*), pine (*Pinus*) and paulownia (*Paulownia*).

The economic crops, such as rubber tree (*Hevea*), tobacco (*Nicotiana tabacum*), and the rhizome of large headed atractylodes (*Atractylodes macrocephala*) have been also planted with tea plants.

The food crops and forage crops which have been intercropped with tea plants are corn (*Zea mays*), sweet potato (*Ipomoea batatas*), potato (*Solanum tuberosum*), barley (*Hordeum vulgare*), wheat (*Triticum aesitivum*), buckwheat (*Fagopyrum esculentum*), pulse family (Leguminosae), peanut (*Arachis hypogaea*), and milk vetch (*Astragalus*). Vegetable crops such as radish (*Rhaphanus sativus*) and wild cabbage (*Brassica oleracea*) have also been intercropped in tea plantations.

Microclimate Character In Tea Plantation Interplanted With Trees

Light Intensity -

The light intensity in the tea-tree intercropping system was 20-30% lower than in pure tea plantation. At noon time in summer, the radiation penetrating through the forest tree crown was only 60-70% in interplanting systems compared to the control.

Temperature -

Intercropping decreased the range of temperature variations (daily and vertical changes). Figure 1 shows the vertical temperature variations measured at different times of day.

Humidity and Wind Speed -

With comparison to the pure tea plantation, the relative humidity increased 2-5% in tea-tree interplanting system. There was a decrease of 10-20% of wind speed in the interplanting system compared to the control.

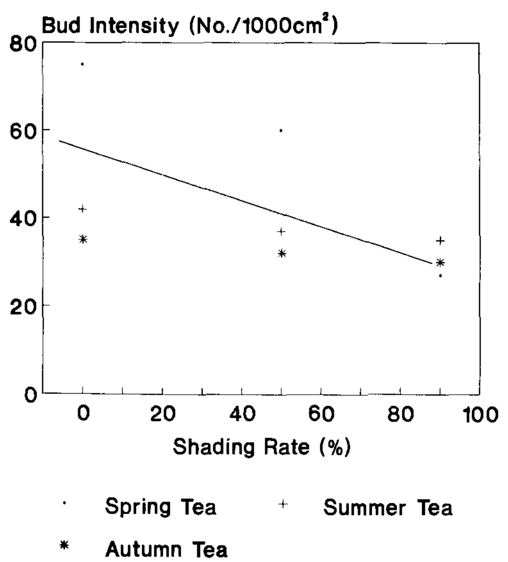

Fig. 2 The Influence of shading on the density of tea buds of Longjing tea. 1 - spring tea; 2 - summer tea; 3 - autumn tea.

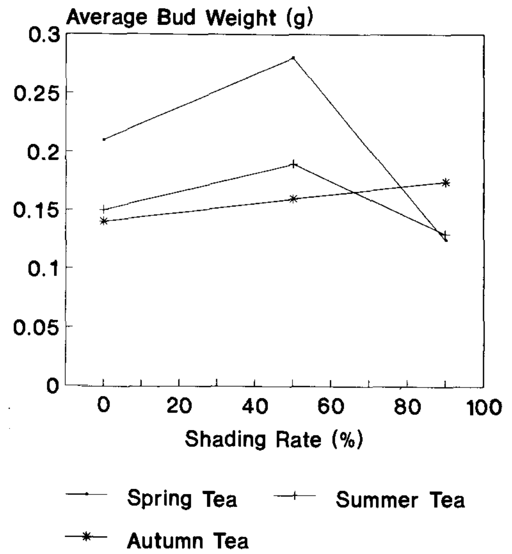

Fig. 3 The influence of shading on the average weight of tea buds of Longjing tea. 1 - spring tea; 2 -summer tea; 3 - autumn tea.

The Physiological and Biochemical Characteristics of Tea Plants Interplanted Under Forests

To study the physiological and biochemical changes of tea plants interplanted under trees, a model experiment was installed in Yuhang, Zhejiang Province (30°N). The planting densities were determined by the following formula:

whereS - Shading degree in percent; I_i - Light intensity of interplanting system; I_c - Light intensity of control.

The tea varieties used in the experiment were shrub type Longjing tea and Small Arbor type Fuding tea. The treatments were S = 0, 50 and 90 for Longjing tea, and S = 0, 30, 50, 75 for Fuding tea. The experimental results from 3-year monitoring are summarised.

Growing Characteristics of Tea Shoots -

Compared to the control, the density of tea buds in the interplanting system decreased by 15.2 to 36.4% respectively for 50% and 90% shading conditions. The buds in the interplanting system were more vigorous. The weight of 100 buds decreased 10.2% in 90% shading condition compared to control. However, the buds under 50% of shading condition grew much better than in the control. The density and average weight of buds were the main factors that affect the yield and quality of tea. As shown in Fig. 2, the density of buds decreased in the shading conditions. However, the average weight of buds was much higher in 50% shading than in control and under 90% shading. The growth and development of tea sprouts varied at different shading conditions. Under shading conditions, the thickness of whole leaf, upper cuticular layer, palisade and spongy tissues decreased, but the ratio of palisade tissue to spongy tissue increased which means shading conditions caused the increase of the proportion of spongy tissue (Table 1) (Fig 3).

Physiological Characteristics of Tea Shoots -

The photosynthetic efficiency of tea plants decreased under the shading condition due to the reduction of light. Under high temperature and dry days in summer, suitable shading increased the photosynthetic efficiency (Fig. 4). On the other hand, under shading conditions, the respiratory intensity and transpiration intensity decreased because of the lower temperature and light intensity (Table 2). Therefore, under strong light conditions, proper shading was beneficial to tea plants' growth due to the increase in effective photosynthetic efficiency.

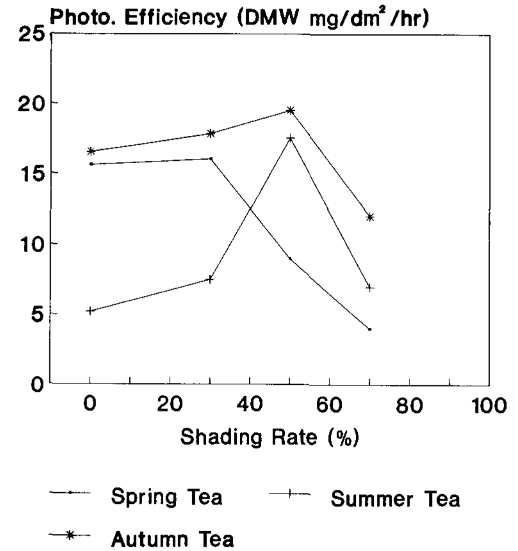

Fig. 4 The influence of shading on the photosynthetic efficiency of tea plants (Fuding variety).

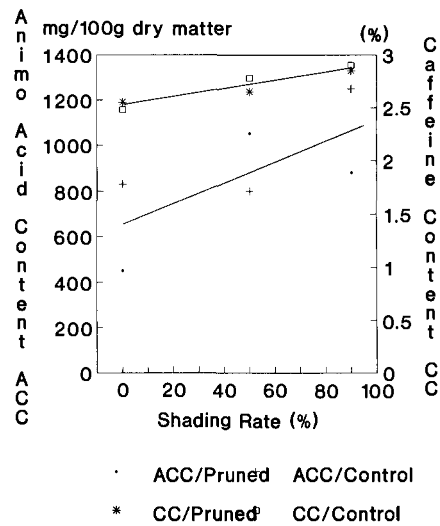

Fig. 5 The influence of shading condition on the amino acid content (1, 2) and caffeine content (3, 4) of Longjing tea shoots. (1, 3 - tea plants pruned before spring; 2, 4 - tea plants not pruned before spring).

Biochemical Changes under Shading Condition -

There was stronger nitrogen metabolism in shaded tea plantations compared with control. The total amino acid contents were 34.8% and 55.2% higher respectively in light shading (S = 50) and heavy shading (S = 90) condition compared to the control (Fig. 5). The caffeine content in tea shoots also increased with the shading degree. The catechin content decreased in shaded tea plantation due to the decrease in respiration (Fig. 6) and the lowering effect was greatest in summer. The water content in fresh tea sprouts increased under shade (Fig. 7). The higher water content was beneficial to prevent the young sprouts from ageing. The chlorophyll content in tea leaves also increased with the shading degree (Fig. 8). Therefore, the photosynthetic efficiency and the utilisation efficiency of light of tea plants under shading was relatively higher, that was particularly obvious on high temperature days.

Integrated Evaluation of Tea-tree Interplanting

Beneficial and Harmful Aspects -

Both beneficial and harmful aspects were obvious in tea interplanting. One benefit was the modification of soil conditions. Roots of interplanted trees developed deeply and "cut off" the soil, which improved soil aggregate. After litter decay, soil organic matter increased. Legume crop roots fixed N_2. Organic acid secreted by some forest trees made some insoluble compounds available as nutrients to plants. Another benefit of interplanting was that it reduced water runoff and soil erosion. The last advantage was that it modified the microclimate of the plantation which facilitated tea production. However, trees shaded tea plants and limited solar radiation that lowered photosynthesis in tea plants. Tea plants and trees also competed for nutrition and water. Lastly, certain diseases developed by intercropping.

The Influence of Shading on Tea Quality -

Interplanting of tea and forest trees increased various nitrite compounds in bud leaves and also lowered the polyphenol content which was usually beneficial to smell and taste of green tea. As for black tea, nitrite compound increased caused by shading which improved tea smell and taste, but it lowered the catechin content and resulted in unsatisfactory quality.

Selection of Tree Species and Proper Planting Density -

Proper selection of forest species is a very important factor for the success of tea-tree interplant-

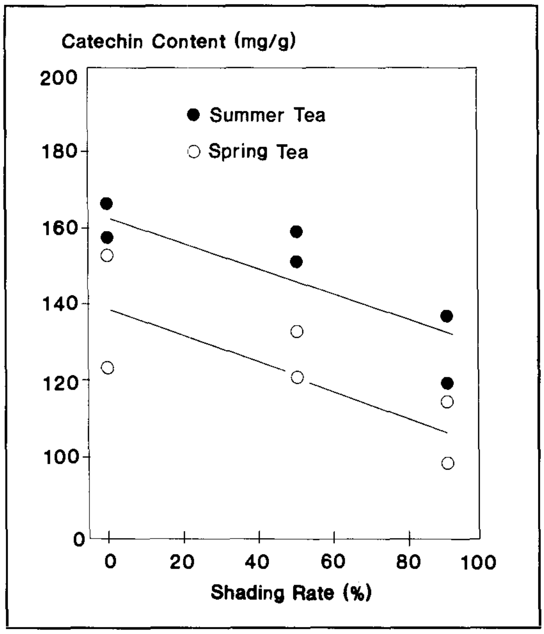

Fig. 6 The influence of shading on catechin content in sprouts of Longjing tea. 1 - spring tea; 2 - summer tea

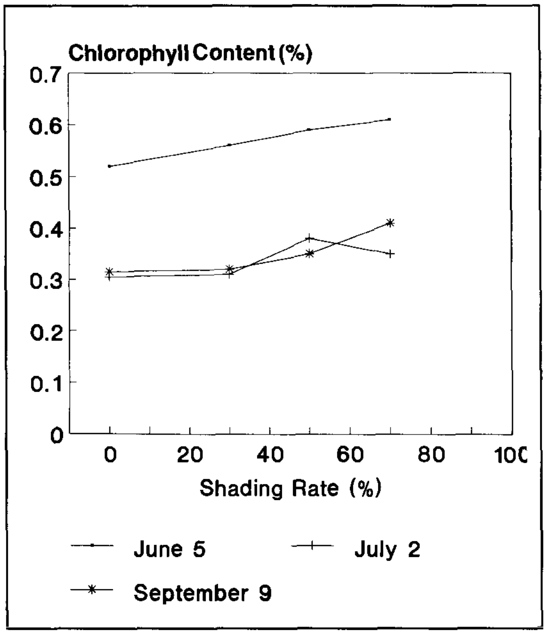

Fig. 8 The influence of shading on chlorophyll content of young sprouts of Fuding tea. 1 - Jun. 5; 2 -Jul. 2; 3 - Sep. 9.

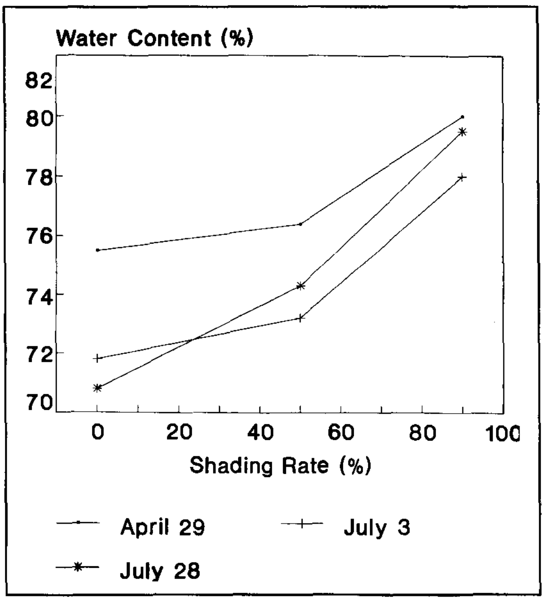

Fig. 7 The influence of shading on water content in young sprouts of Longjing tea. 1 - Apr. 29; 2 - Jul.3; 3 - Jul. 28.

ing. The following criteria should be considered: (a) Should not compete with tea plants for nutrition and water; (b) Should have the capacity to improve soil conditions including increasing soil nutrient status and improving soil aggregates; (c) Should be fast-growing with high economic value; (d) Should not have the same pests and diseases as those of tea plants; and (e) Should be without smell that may lower tea quality.

The planting spacings of shading trees must be optimum. It has been reported that 30-40% shading in rubber tree-tea interplanting system was profitable to dry matter accumulation and improve tea quality. Heavy shading (over 50% shading) caused an obvious decrease of tea yield. In general, it was appropriate that the forest trees produced a shading of 20-45%. The planting spacing was determined by the factors of climate and management measures.

Acknowledgement

The authors thank Professor Q.K. Chen and Z.Z. Wang for their helpful comments.

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Study on the Effects of Shelter Forests in Citrus Orchards

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ABSTRACT

This paper shows the ecological, economic and social effects of shelter forests in citrus orchards. The main effects were reducing wind speed, reducing temperature variation and water evaporation, and increasing air humidity. Compared with a shelterless area, the defoliation ratio and the freeze injury index of the sheltered citrus trees decreased by 7.0-15.5% and 6.5-25.7% respectively, while the height, crown diameter and fruit yield increased by 38.5-72.4%, 6.0-80.7% and 20-30% respectively. Also, a certain amount of forest by-products was obtained from the shelter forests.

Introduction

Freeze injury is a factor limiting the high yield and good quality of citrus production in the cultivation areas in north China. Establishment of shelter forest is an effective measure in protecting citrus trees from freeze and drought injury (Huang, 1983). Arobelitje *et al.* (1977) reported that there were 18,600 ha of sheltered citrus orchards in the U.S.S.R. and the yield was 20% higher than that of shelterless ones.

The effects of shelter forests on meteorological elements and crops in sheltered areas have been reported (Cho, 1983; Konstangenov, 1983). However, the effects of shelter forests on meteorological elements and economic benefits of citrus have not been reported in detail. We carried out the experiments in the winters of 1981-1984, in Shanghai City and Zhejiang Province. The results are summarised in this paper.

Materials and Methods

Experiments were conducted on the citrus orchards of Qianwei Farm, Shanghai (31.5°N) and Jinhua, Zhenjiang Province respectively. The former orchard is found on an island situated on the outlet of the Yangzi River found on a low hillside in an inland area. The citrus used in the experiments was *Satsuma*. The main species of shelter forests (= trees, belts) were *Viburnum awabuki*, *Metasequoia glyptostroboides* in Shaihai and *Cunninghamia lanceolata* in Zhejiang. The main and sub shelter belts crossed to form a rectangular net, measured 30 x 50 m. Wind speed, air and soil temperature, air relative humidity and evaporation were measured at various distances from the shelter trees in windward and leeward sides, and the citrus orchards without protection of shelter belts which were selected as control. Freeze injury surveys were conducted in the next spring. Naked-eye observation showed that there were six classes of injury degrees divided from without freeze injury to completely dead. The freeze injury index (Y) was determined by the following formula according to the data:

$$Y = \frac{1a_1+2a_2+3a_3+4a_4+5a_5}{6(a_0+a_1+a_2+a_3+a_4+a_5)} \times 100\% \qquad (1)$$

where1, 2, ... are the freeze injury classes, and a_0, ..., a_5 are the corresponding number of citrus trees suffering from freeze injury. Tree height, crown diameter, girth of main stem and number of fruits were measured or counted in autumn.

Results

The distribution of meteorological elements in the sheltered citrus orchards was significantly dif-

Table 1. The influence of shelter forest on temperature in citrus orchards (^{0}C)

Meteorological elements	Sheltered citrus orchard Windward	Sheltered citrus orchard Leeward	Shelterless citrus orchard
Daily mean air temperature	3.5	4.0	3.1
Daily maximum air temperature	8.0	8.9	7.2
Daily minimum air temperature	0.0	0.6	-0.4
Daily mean soil temperature	3.7	4.4	3.3
Daily maximum soil temperature (0cm)	9.1	10.0	8.3
Daily minimum soil temperature (0cm)	0.3	0.9	0.1
Daily mean soil temperature (10cm)	4.3	4.8	3.9

Table 2. The influence of shelter forest on evaporation and air relative humidity in citrus orchards

Site	Evaporation (mm)			Relative humidity %	
	3m from forest belt	10m from forest belt	Control	Sheltered garden	Control
Qianwei	2.7	2.9	3.9	85	76
Jinhua	-	-	-	93	89

Table 3. The influence of shelter forest on the defoliation ratio of citrus trees

Distance from shelter (m)	3	9	15	30	45	Control
Wind speed (m/s)	2.3	2.4	2.5	3.1	3.7	5.6
Defoliation ratio (%)	4.6	4.9	5.9	9.8	13.1	20.1

ferent from that in the shelterless ones and details were as follows.

Reducing Wind Speed -

Reducing wind speed was an important function of shelter forests. Figure 1 shows that whether on a fine day or a cold day, the decrease of wind speed took place at a distance of 10 H (H is the height of shelter forests) from the shelter in the windward side and the minimum wind speed occurred at the distance of between 0-10 H from the shelter in the leeward side. The wind speed increased with distance from the shelter and was up to the value similar to the shelterless area at the distance of about 25 H from the shelter. Also, Fig. 1 shows that the influence of the shelter forests on wind speed was more remarkable on a cold front day than on a fine day.

The influence of shelter forests on wind speed was associated with the structure and height of trees and the angle between the shelter belt and the wind direction. Generally, the porous shelter belt can most effectively reduce the wind force. The higher the shelter, the larger the sheltered area. The more rectangular the angle between the shelter and the wind direction, the lower the wind speed on the windward and leeward sides. There were three kinds of shelter belts on the Qianwei Farm: One was composed of *Metasequoia glyptostroboides*, the second of *Viburnum awabuki* and the third was composed of both the above and bamboos. The former two kinds of shelters were less effective in reducing wind force due to the defoliation in winter and the massive density of the latter. However, the last one did reduce the wind force due to its proper structure (Fig. 2).

Reducing Temperature Variation -

The influence of shelter belts on the temperature of the sheltered area, on the whole, was remarkable and depended on the shelter belt's structure, net's size, water supply in the net, ground slope and fruit tree's physiological state, etc. On a fine day, the temperature of the sheltered citrus orchard was higher in the daytime and lower at night as compared to the shelterless one due to the reduction of turbulence of air near the ground in the sheltered citrus orchard. On the Qianwei Farm, for

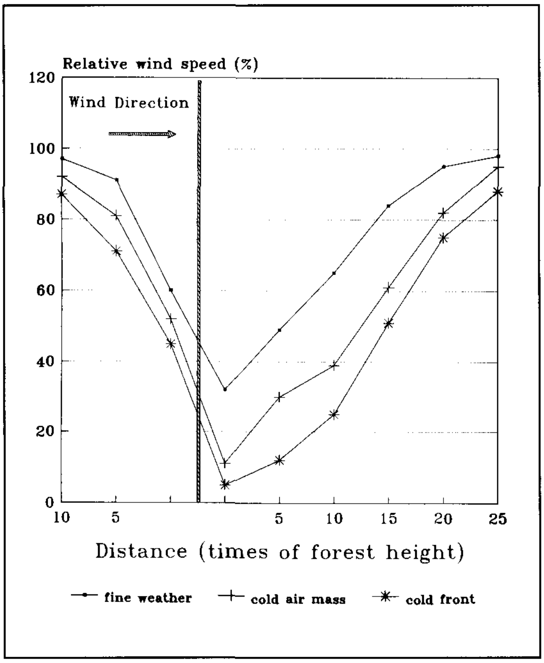

Fig. 1 The influence of shelter forest on the wind speed in citrus orchard. 1 - fine day; 2 - cold air mass; 3 - cold front; 4 - wind direction.

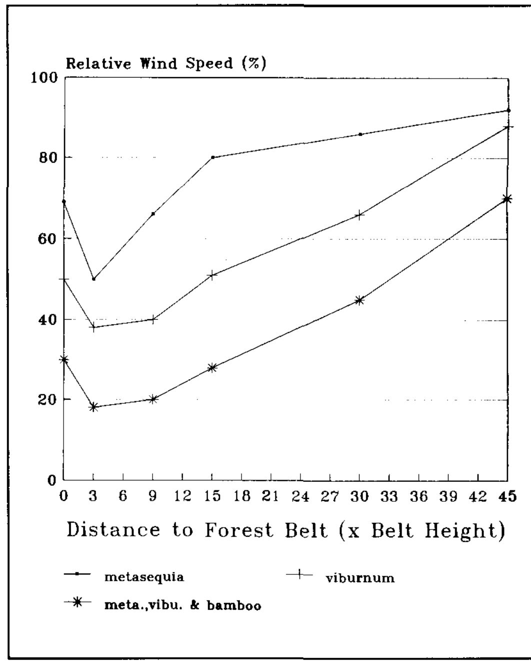

Fig. 2 The influence of various shelter forests on the wind speed on the leeside. 1 - Metasequoia; 2 - Viburnum; 3 - Metasequoia + Viburnum + Bambuseae.

instance, the relation between minimum temperature of the sheltered citrus orchard (Y_f) and that of the shelterless one (X_f) was as follows on a fine day in winter:

$$Y_f = -1.25 + 0.98X_f \text{ (n=54, r=0.974)} \quad (2)$$

and on a scattered or rainy day in winter the relation was:

$$Y_c = -0.91 + 1.03X_c \text{ (n=37, r=0.974)} \quad (3)$$

However, in citrus orchard on a mild slope the daily average air and soil temperatures were higher on the leeward slope than those on the windward slope with the latter being higher than those in the shelterless area because of the shelter reducing wind speed during the cold air as well as the slope draining the cold mass away during the radiation cooling (Table 1).

Increasing Humidity and Decreasing Evaporation -

The humidity and the evaporation in the sheltered citrus orchard was higher and lower respectively, than those in the shelterless one, because the shelter decreased wind speed, turbulence and soil-water evaporation which resulted in vapour staying in the citrus orchard (Table 2).

Shelter Forest Preventing Citrus Orchard from Freeze Injury -

In the north edge of the citrus cultivating area in China, the tree injury in the winter is classified into freeze damage and cold damage. The former is caused by the temperature being lower than the lowest temperature for a citrus tree to survive. The latter results from a great deal of defoliation due to the physiological dehydration which takes place when a cold wind blows with higher temperatures for citrus trees to survive (Wu and Huang, 1986). Wind speed and air humidity are the main factors influencing cold injury to citrus trees. It was reported that the minimum defoliation ratio occurred when the maximum wind speed was lower than 7 m/s, and defoliation ratio significantly increased when wind speed was higher than 7 m/s (Onaka Genma, 1966). Reducing wind speed was most effective of the shelter forest which reduced the cold wind injury and the defoliation ratio of the sheltered citrus trees. The ratio of defoliation of the sheltered citrus orchard was 7.0-15.6% lower than that of shelterless citrus orchard (Table 3). After growing the shelter belts in the citrus orchard, the wind speed decreased and the temperature and humidity increased which resulted in the reduction

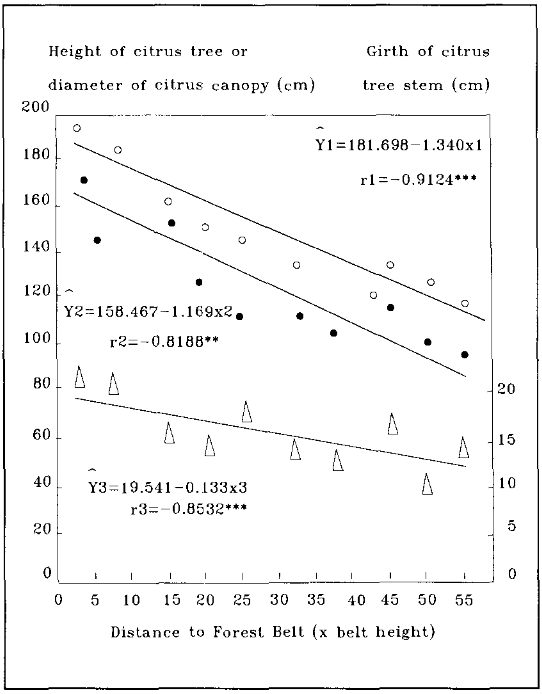

Fig. 3 The relationship between height (1), crown diameter (2), stem girth (3) of citrus trees and the distance from citrus tree to the shelter forest.

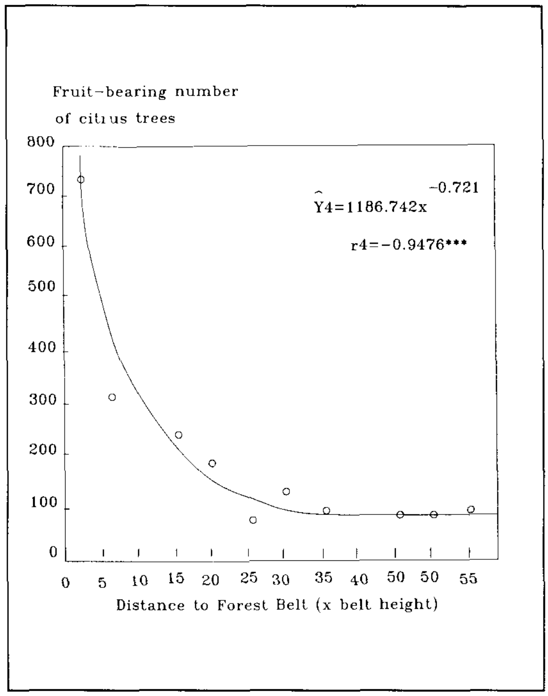

Fig. 4 The relationship between the number of fruit-bearing citrus trees and the distance to the shelter forest.

of freeze injury, and it was lower than that of the shelterless one by 6.6-25.7% in the freeze injury index (Table 4).

The Influence of Shelter Forests on the Growth, Development and Fruiting of Citrus Trees -

The shelter forest improves the orchard's microclimate so that the sheltered citrus trees with larger crowns grow better than the shelterless ones (Table 5). In Zhejiang Province, the late maturing *Satsuma* citrus trees planted on the leeward side of the shelter forests had higher heights and crown diameters of 38-73% and 6-80% respectively than those planted on the windward side and in open fields (Fig. 3).

In sheltered citrus orchards, citrus tree height (Y_1) and crown diameter (Y_2) was linearly related to the distance from the shelter forest (X), with the relative coefficient r_1 = -0.9124 and r_2 = -0.8188 respectively, as does citrus tree stem girth (Y_3) with the relative coefficient r_3 = -0.8532 (Fig. 3). Citrus tree fruit bearing number (Y_4) exponentially related to X with the relative coefficient r_4 = -0.9476 (Fig. 4). On the whole, nearer to the shelter belt (except for the row of citrus trees beside the shelter), higher the citrus trees, larger the crown diameter and main stem, and higher the fruit bearing quality.

The Integrated Evaluation of Shelter Forests on Citrus Orchards -

The shelter forest improves the ecological conditions which results in increase of fruit yield and early fruiting. On the Qianwei Farm, Shanghai, two orchards were built in 1979, one with shelter forest, the other without. The fruiting in the former was one year earlier than in the latter; and fruit yield was 3.3 times higher in the former than the latter (Table 6). The difference was smaller in the years without severe natural damages (such as freeze and drought). One year of freeze injury influenced the yields in the next two or three years even if no freeze injury occurred the very next year. In Houda Commune, Zhejiang Province, freeze injury took place in the winter of 1979-1980, when freeze injury index of the sheltered citrus orchard was 38.0% while that of the shelterless one 55,7%. Two years later, the former's fruit yield was 9,000 kg/ha and in the latter 2,250 kg/ha.

The Economic Benefit -

The shelter trees are usually planted around the orchards, beside water and along both sides of roads to form a net which promotes ventilated

Table 4. The influence of shelter forest on freeze injury of citrus trees.

Site/Observation Season	Treatments	Number of observed trees	Freeze injury index (%)
Qianwei Farm, Shanghai/ Spring, 1982	Sheltered	100	6.0
	Control	100	20.6
Dongxiao Commune, Zhejiang/Spring, 1984	Sheltered	200	38.0
	Control	140	55.7
Houda Commune, Zhejiang/ Spring, 1984	Sheltered	156	53.2
	Control	130	78.9
Xiekuang Commune, Zhejiang/Spring, 1984	Sheltered	20	41.0
	Control	16	47.5

Table 5. The influence of shelter forest on growth and development of citrus trees.

Item	Tall(4.3m) shelter forest	Short(2.3m) shelter forest	Control
Total height (m)	1.69	1.22	0.98
Crown height (m)	1.57	1.13	0.88
Stem girth (m)	0.19	0.14	0.08
Crown diameter (m)	1.59	1.50	0.88
Thickness of green leaf layer (m)	0.66	0.38	0.29
Total crown volume (m^3)	2.39	1.41	0.41
Effective crown volume (m^3)	2.03	0.96	0.31

condition with rich light and fertile soil, so that the trees can grow rapidly and produce greater amount of wood. In Zhejiang, the shelter tree (*Cunninghamia lanceolata*) planted in February 1978 grew to the height of 5-10 m with maximum stem diameter of 10-15 cm and timber volume of 27 m^3/ha by the spring of 1987. In Shanghai, the shelter trees (*Metasequoia glyptostroboides*) were planted in spacing of 1 x 1 m. The trees reached an average height of 4 m when some of them were transplanted in the second year.

The Influence of Shadow and the Stressland -

The shelter forest shadow falls on citrus trees and reduces the solar radiation and decreases the photosynthetic intensity and fruit yield. The distance of the shadow edge from the shelter forest (D) can be determined according to the following formula:

$$D = L \times \sin(A + \beta) \qquad (4)$$

whereL - length of shadow; A - azimuth of sun; B - azimuth of shelter belt. A and L can be calculated by the following formulae:

$$\sin A = \frac{\cos\theta \times \sin\omega}{\cos h} \qquad (5)$$

$$L = H \times \mathrm{Ctg}h \qquad (6)$$

whereH - height of shelter belt; , D, and h - declination, time angle and altitude of sun respectively. h can be calculated as follows:

$$\sin h = \sin\phi \times \sin\theta + \cos\phi \times \cos\theta \times \cos\omega \qquad (7)$$

where ϕ is the latitude of the orchard. The result, obtained according to the formulae (4)-(7), showed that in China, the maximum shadow range and time of shelter forest occurred in winter and the minimum in summer; for the north-south shelter belt, both sides had the same shadow range and time; for the east-west one, that of the north side was more than that of the south side; for the northeast-southwest one, the northwest side was more than the southeast side.

Table 6. The influence of shelter forest on fruiting age and yield of citrus orchards.

Item		Sheltered orchard	Shelterless one
Area (ha)		2.73	3.03
Number of citrus trees		5,526	5,189
Percentage of	1981	65	0
fruited trees (%)	1982	94	75
Fruit yield (kg)	1981	15,946	0
	1982	36,184	23,857
	Total	52,130	23,857

The area that affected the root system and shadow of shelter forest is called stressland. The competition for water and nutrition between the root systems of citrus tree and shelter tree without irrigation and adequate fertiliser was more significant than that in the one with them. The stressland on both sides of shelter belt ranged from 1-1.5 H. In Zhejiang, for instance, two rows of citrus trees next to the shelter (*Cunninghamia lanceolata*) with a height of 5 m, had a fruit yield 15-20% lower than the ones not affected by the shelter. This disadvantage could be avoided by means of digging a deep canal around the shelter and removing some leaves from the lower part of the shelter trees. If the area of shelter net was up to 1 ha or more, the fruit yield deceased by 1,125 kg/ha due to the stressland's effect.

The direct economic benefit of the shelter forest was with the yield of wood and forest by-products and indirect effect was improving the orchard's ecological environment and increasing the fruit yield by 20-30%. In addition to the above effects, shelter forest played a bigger role in recovering and conserving the natural ecological balance.

Conclusion

Building a shelter forest was an effective means of improving the favourable microclimatic conditions for citrus tree growth and fruit production.

The most significant effect of shelter belt was to decrease the wind speed and turbulence by 30%. The influence of the shelter belt on temperature varied with weather conditions and topographic conditions. On a fine day in winter, the air temperature in the sheltered citrus orchard on plain area was lower than that in a shelterless one, while the temperature in the sheltered one on a mild slope was 0.4-2.0°C higher than that in a shelterless one. On a cold day in winter, the temperatures in sheltered orchards were higher than that in a shelterless one. The relative humidity and daily amount of evaporation in the sheltered orchard increased by 4-9% and decreased by about 1.2 mm respectively compared with that in shelterless one.

The defoliation ratio and the freeze injury index decreased by 7.0-15.5% and 6.5-25.7% respectively an the height, crown diameter and fruit yield of the citrus tree increased by 38.5-72.4, 6.0-80.7 and 20-30% respectively compared with those in a shelterless orchard. Also, the shelter forest supplied man with timber and forest by-products. At the same time, the shelter forest played an important role in improving and conserving natural ecological balance.

Acknowledgement

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Study on the Cultivation of Mushrooms in *Paulownia* Plantations

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ABSTRACT

Growing Lentinus edodes under Paulownia plantings is a new method of mushroom cultivation. The environment was suitable for the growth of mushrooms due to the modified microclimate by the shading of the Paulownia canopy. At the same time, the residues from forest harvests were used for preparation of nutrient substratum for mushroom cultivation and substratum materials were returned to the soil as fertiliser after mushroom cultivation. The forest residues were fully used and lowered the cost of mushroom cultivation, which was highly economical and ecologically a sound technique in forest areas.

Introduction

Lentinus edodes is a delicious, nutritious, and completely edible fungus. The optimum conditions for growth are 80-90% relative humidity, a 5-15°C in temperature range for the low temperature type and 10 - 20°C for the medium temperature type. It is one of the most popular cultivated mushrooms with an annual yield of 14% of the total edible mushrooms (15 million tons) cultivated in the world. The experiments were carried out in Muchuan County of Sichuan Province which is a promising area for the development of mushroom production because of the suitable climatic conditions for mushroom growth and the plentiful forest residues from both the harvest and processing that is a potential source of culture media. The objectives of the experiments were to compare the performance of *Lentinus edodes* under green house, ordinary house and tree shading conditions and study the adaptability of *Lentinus edodes*.

Materials and Methods

Site Selection -

Five-year old plantations of *Paulownia* and *Catalpa* with planting spacing of 6 x 8 m and canopy density of 0.6 were selected for the experiment. Mixed forest area of *Paulownia* and *Cryptomeria* was used in another pilot experiment.

Eighteen varieties of *Lentinus edodes* provided by the Sichuan Provincial Academy of Agriculture were used in the experiment. Numbers 16 and 17 were screened as the best varieties for extensive cultivation.

Preparation of Culture Substratum and Production -

The following materials were used for preparation of culture substratum. *Trial:* Sawdust 80%, rice bran 15%, corn flour 3%, gypsum 1% and sucrose 1%. *Extensive cultivation:* Sawdust 78%, rice bran 20%, gypsum 1%, sucrose 1% and additional 0.1% fungicide with water content of 55-60%, pH 6-7.

The following procedures were followed in preparation of culture substratum: Mixing - packing (1 kg air dried substratum per plastic bag) - sterilising (normal air pressure, 100°C for 8-10 hours) - inoculating - germinating - removing bag - mushroom planting under trees - management - harvest.

A comparison trial experiment was conducted between different culture conditions, i.e., mushroom cultivation in green house, ordinary house and under forest conditions, at the first stage. Another experiment was conducted under *Paulownia* forests. The comparative trial was con-

Table 1. Yield of *Lentinus edodes* in different environmental conditions

Year	Total	1985						1986						
Month		Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul. Sep.
Green house	3.49		0.05	0.24	0.96	0.17	0.31	0.49	0.12	0.38	0.41	0.25	0.11	
Ordinary house	7.01			0.13		0.16	0.10			0.27	0.73	2.57	2.08	0.97
Forest	10.07	0.24	0.38	1.22	4.61	0.42	0.23	0.20	0.06	0.56	0.49	0.09	0.02	1.55

Table 2. Biological efficiency at different environmental conditions

Block	I	II	III	IV	Mean
Green house	0.269	0.207	0.327	0.273	0.269
Ordinary house	0.320	0.258	0.397	0.304	0.320
Forest	0.476	0.551	0.400	0.313	0.435

Table 3. ANOVA analysis result of data in Table 2

Resource	Sum of square	d.f.	Mean of square	F-ratio	F0.05
Treatment	0.058	2	0.029	4.14	5.14
Block	0.010	3	0.003	0.43	4.76
Error	0.039	6	0.007		
Total	0.107	11			

ducted from June 1985 to September 1986 with three treatments (green house, ordinary house and forest) and four replications in a randomised block design method. Three hundred bags of *Lentinus edodes* with spacing of 10 x 30 cm were cultivated in each plot. Meanwhile, 314 bags were placed under *Catalpa* forest with 10 cm distance between each bag. The extensive trial started in May 1987. 5,267 bags of *Lentinus edodes* variety 16 were grown in *Paulownia* plantations and another 17,500 bags were placed in forest stands for production. Clearing grass and sterilising soil by spreading lime was done before arranging the bags. The critical period was before harvesting when the water content of the mushroom was lower than 30-50% or when fine weather continued for three to five days. The hole-opening irrigation or immersion was done to increase water content to 60% or higher. The weeds were removed.

Data Collection and Analysis -

A thermometer screen was mounted inside the plantation during the growing season of *Lentinus edodes* to record temperature, humidity, radiation, rainfall and rainy days. The mushroom yield for each plot was recorded during harvest. The following formulae were used to compute biological efficiency:

whereEs - biological efficiency of single cultivating bag; Et - total biological efficiency; MWs - mushroom weight of single bag; MWt - total mushroom yield; SWs - inoculated substratum weight of single cultivating bags; and SWt - total inoculated substratum weight.

Results and Discussion

The yields of mushrooms from the three treatments (green house, ordinary house and forest) are listed in Table 1 and the computed results of biological efficiency is indicated in Table 2. ANOVA shows that no statistical difference between the three treatments (Table 3). 5,267 cultivating bags (total inoculated substratum of 621.8 kg) were placed in *Paulownia* plantations on May 22, 1987 and the yield in 1988 was 2,136.94 kg, that reached 59% in biological efficiency (Table 4). The yield of mushrooms planted in April 1988 is listed in Table 5. Started in the spring of 1988, 50,820 cultivating bags (equal to 36,590.4 kg inoculated substratum) were placed in forest stands and the total yield reached 25,548.7 kg. The biological efficiency was 69.82%.

The results showed that *Lentinus edodes* growth and yield were mainly effected by temperature, humidity and light (Fig. 1).

Temperature - Under forest conditions, mushrooms were harvested on July 31. On an average, 1 kg inoculated substratum produced 0.435 kg mushrooms. Seventy percent of the total yield of mushrooms occurred in August to October. In the green house, mushroom harvest started one month later, on August 31 and temperature in the green house was reduced to what it was in the forest one month previously. The average mushroom yield of 1 kg inoculated substratum was 0.253 kg. Mushrooms can grow in temperatures ranging from 5-

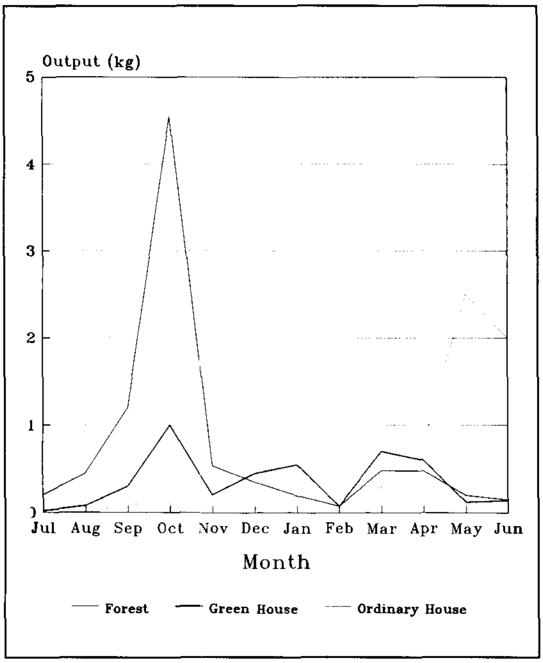

Fig. 1 Yearly growth pattern of Lentinus edodes under different cultural conditions

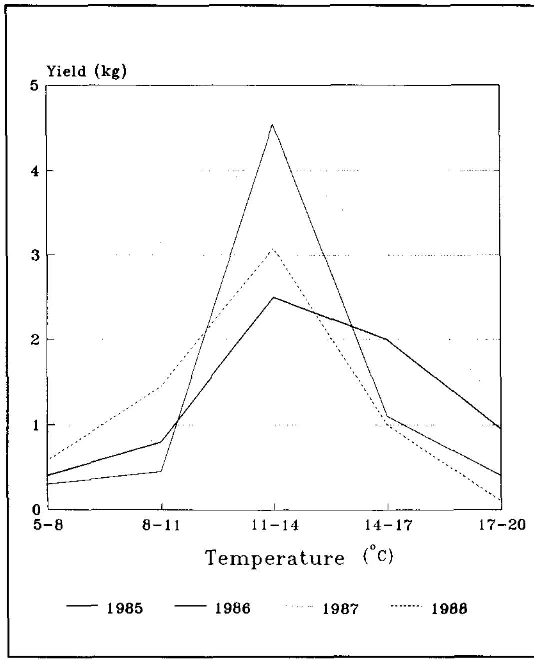

Fig. 2 The relation between growth of Lentinus edodes and temperature

20°C. Figure 2 indicates the relationship between temperature and mushroom yield. The most suitable range of temperatures for the growth of mushrooms was 8-16°C.

Humidity - In the experimental area, the rainfall was high and the average number of annual rainy days was 265. Usually there are only four fine days in September and the average relative humidity was 93% which promoted high yields in the forest. The humidity in the green house was variable since it depended on water spray.

Light - The growth of *Lentinus edodes* required some indirect light and the light was insufficient in an ordinary room. Thirty-six inoculated bags produced only 0.34 kg of mushrooms in the first year inside the ordinary room in 1987. After transplantation to the forest in second year, they grew and the yield was 14 times higher than in the first year. The research results also showed that the microclimate under *Paulownia* plantations with a canopy density of 0.6-0.7 were suitable for the growth of *Lentinus edodes* and the biological efficiency was greater than 59%.

The Potential for Extension and Extensive Development

It was reported that the total edible mushroom yield was 150 million tons in 1985, of which *Lentinus edodes* accounted 14%. The yield of *Lentinus edodes* raised 20-30% of the total world's edible mushroom yield in five to ten years. The main producing countries are China and Japan. The price of Chinese *Lentinus edodes* is half to one third lower than the Japanese, so China has been the main exporter of *Lentinus edodes* to Hongkong and

Table 4. Mushroom yield under *Paulownia* plantation inoculated in 1987 (unit: kg)

Year	1987							1988		
Month	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Yield	51.30	80.45	124.15	320.55	452.40	328.30	82.15	51.30	22.77	139.85
Year	1988									
Month	Apr.	May	Jun.	Jul	Aug.	Sep.	Oct.	Nov.	Dec.	
Yield	321.33	104.00	17.40	14.00	2.35	12.45	8.00	4.49	0.50	

Table 5. Yield of mushrooms inoculated in 1988 under *Paulownia* plantations (kg)

Month	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Yield	14.30	26.50	32.30	36.15	131.35	144.75	52.46	3.70

South East Asia. So *Lentinus edodes* has a very strong competitive potential in domestic and international markets.

Economic Benefit -

In large scale production of *Lentinus edodes*, the cost including the materials and labour for preparation, management and harvest was 0.8-1.0 CNY/bag, one inoculated bag produced 0.6 kg mushrooms valued at 1.44 CNY, giving a net profit of 0.44-0.64 CNY/bag. Ten thousand bags covered 0.067 ha and gave a net profit of 5,000 CNY. The value of the mushrooms increased by 30-50% through processing. With the influence of the experiment, Muchuan County developed *Lentinus edodes* specialised households and three companies. They cultivated 147,279 bags of *Lentinus edodes*. The biological efficiency increased. People gradually realised the benefit of mushroom cultivation.

Improvement of Cultivation Sites -

Proper selection of *Lentinus edodes* varieties is necessary and these should grow well under the conditions of high humidity, resistant to infection, high adaptability, and high yield.

Broad-leaf forest and mixed planting forest of broad-leaf species and needle-leaf species with a canopy density of 0.6-0.7, abundant water supply and grass growing were considered as good sites for the growth of *Lentinus edodes*. Meanwhile, sterilisation of soil using lime and cutting high grass were also necessary before planting of *Lentinus edodes*. It was necessary to use comprehensive methods to improve the quality of planting materials and proper procedure to keep the infection rate under 10%. With a consistent water supply, pest and disease control, and fertiliser application were necessary to increase the biological efficiency. Timely harvest and adapting advanced mushroom processing technology would yield higher profits.

Harnessing the Lime Concretion Fluvo-aquic Soil

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ABSTRACT

The lime concretion fluvo-aquic soil is one of the poor low yielding soils affecting the development of agriculture in the Hang-Huai-Hai Plain. The area is about 3,133,300 ha, one-sixth of the total area in Huang-Huai-Hai Plain. The main reason for low yield is drought, flood and salinisation. It has been shown that the best way to improve the soil is by means of integrated measures of irrigation and agrobiological control combinations. This is based on water conservancy to improve the fertility of the soil through biological measures, to reach a comprehensive method to harness the soil.

Introduction

The lime concretion fluvo-aquic soil has low agricultural productivity in the Huang-Huai-Hai Plain. The area of the lime concretion fluvo-aquic soil is 3,133,300 ha, among which 2,333,300 ha about one-sixth of the total farmland. It is widely distributed over the northern provinces of Anhui, Shandong and Jiangsu, mainly in the Huaibei Plain of Anhui Province.

The Huang-Huai-Hai Plain is rich in solar radiation, abundant in rainfall and underground water resources with flat ground and deep soil that is suitable for the growth of many agricultural crops. But the agricultural yield is very low due to the infertile lime concretion fluvo-aquic soil and the current yield is around 3,000 kg/ha/yr. Calculated on an average increase of 2,250 kg/ha/yr in agricultural yield, the yield will increase over 5 million tons/yr.

Reasons of Low Yield and Main Problems

The main reasons for low yield are the soil's susceptibility to drought, flood and salinisation and other related factors are climate, topography, hydrology and agricultural practices.

The lime concretion fluvo-aquic soil is developed from the half damp meadow clay soils in the warm-temperate zone. At the beginning, bad drainage conditions impeded the flow of surface water and underground water, then the salt-tolerant meadow plants grew there. Under climate of alternating dry and wet condition, the soil was clayed and calcium carbonate was leached and deposited. This process formed a two-soil layer, the black soil in the upper layer and lime concretion under the black soil, and this was called lime concretion fluvo-aquic soil, which was of poor constitution, physical features and low nutrient levels. The cultivated level was only 12 cm in depth and the plough sole was 15-20 cm in depth and hard. The volume weight of the cultivated horizon was 1.4 g/cm^3, and that of other soil layers was over 1.5 g/cm^3. The total porosity and aerated porosity were 47% and 8% respectively of the cultivated horizon and 45% and 2% for other soil layers. The porosity condition and the plough sole layer impeded penetration of water. The content of clay particles in cultivated horizons was 22.95% which was lower than in other soil layers. But there is a high content (57%) of silt particles. The soil was hard in drought conditions, and muddy in wet conditions, resulting in bad cultivability with short cultivation period (three to five days). The nutrient level of the soil was also very low, the average organic matter content of the cultivated layer was 1.1%, total nitrogen 0.073%, total phosphorous 0.094%, available nitrogen 51 ppm and available phosphorous 2.53 ppm.

The area belongs to the semi-humid monsoon climate in the warm temperate zone. As the monsoon is unstable, annual rainfall is not well distributed. In the rainy season (June-September), rainstorms occur frequently that bring about floods. In the dry season (spring and autumn), the rainfall is very sparse and often with dry, hot winds that cause serious damage to the agricultural crop's growth and development. The traditional agricultural production is a monocrop farming system on the lime concretion fluvo-aquic soil. It is a non profitable landuse system due to the over-use of land and serious imbalance of the agribio-ecosystem.

The Methods of Harnessing the Soil

Water Conservation -

Water conservation is a very important factor for improving the low yield farmland. The main reason for low yielding agricultural crops is the frequent floods and droughts. The water conservation system should include drainage, irrigation capacity and water storage. Since 1949, many big canals have been dug that gradually extended the area of drainage, but it has not been completed so it is not in full use. In the rainy season, the water cannot drain quickly, so the floods are not under control. For a complete water control system, big canals and small canals must be dug to connect all the canals as a network. The water should drain quickly in the rainy season to control flooding.

Because the rainfall is not well-distributed in the area, droughts also occur in the dry seasons of spring and autumn. The water storage is important. Over drainage of cropland in the rainy season can be prevented improving the underground water table. The big canals can be used to store water to control the underground water table at 1.5 m. In the dry season, the underground water is the main water source for irrigation because of its low table (1.5-2.5 m), and good quality (with mineralisation degree less than 0.5 g/l). Shallow well (5-6 m in depth) irrigation is a very successful practice that is easy to work (no special tools needed), low cost (60-70 Chinese Yuan (RMB)/well) and high efficiency (8-10 m^3/hr, irrigating 0.1-0.14 ha/dy).

Biological Measures -

Combined with the capital construction of farmland, establishing a systematic protective forest system is one of the most important biological measures in the area. Under the protection of the system, the microclimate of the farmland is improved. That results in an increase of agricultural output. At the same time, the protective system can provide the local growers with timber, fodder, firewood, green manure and so on that promote the development of animal husbandry and alleviate the problems caused by shortage of forest resources.

Green manure planting - In order to raise the nutrient level of the soil, green manure should be used to provide the soil with more organic manure. The main green manure species suitable for planting in that area are false indigo, *Sesbania*, Chinese milk vetch, Chinese trumpet creeper, etc. Planting the above species produce green manure and provide fodder for animals.

Regulation of planting structure - New farming techniques such as intercropping, shifting cultivation, etc. should be used to change the planting methods. In this way, the biological efficiency of the landuse system will be increased and soil can be conserved.

Development of animal husbandry - With the development of agriculture, animal husbandry will be an important component in the production structure. Ecologically, animal husbandry is the most reasonable way to use the biomass. Through the food chain, the biomass will be more efficiently used. In a normal circulation, the energy utilisation efficiency can be up to 60%, but only 10% if the biomass is directly burned as firewood.

Fertilisation - With the combination of organic and inorganic fertiliser, the utilisation efficiency of solar energy will be improved, so larger amounts of solar energy will be transformed to biomass. The increased biomass production gives a foundation for the development of animal husbandry, fisheries, etc. As the nitrogen and phosphorous level in the soil is very low, nitrogen and phosphorous fertilisers must be applied in proper amounts. At the same time, agricultural residues should be returned to the farmland to raise the organic matter to improve the structure of the soil.

V. AGROFORESTRY SYSTEMS IN SOUTH SUBTROPICAL AND TROPICAL ZONE

Forest Network of Farmland in Zhujiang River Delta (Guangdong)

Villous Amomum (Amomum Villosum) Interplanted under Rubber trees (Hevea brasiliensis) (Guangdong)

Rubber tree (Hevea brasiliensis) - Tea (Camellia sinensis) Interplanting (Guangdong)

Pineapple Intercropped in Eucalyptus Plantation (Eucalyptus Leizhou No. 1) (Hainan)

The Characteristics and Benefits of Forest Network Farmland in the Zhujiang River Delta

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ABSTRACT

Zhujiang River Delta is a vast subtropical area. Some work has been done to establish farmland forest networks which help to increase biomass and resist typhoons. More intensive afforestation programmes are necessary to grow timber trees and improve agricultural production.

General Description of the Delta

Zhujiang River Delta is located in south of Guangdong Province with largest plain in the southern subtropical zone of China, spread over 17 counties or cities including Foshan, Nanhai, Shunde, Zhongshan, Sanshui, Jiangmen, Xinhui, Gaoming, Guangzhou, Panyu, Zengcheng, Dongwan, Shenzhen, Baoan, Zhuhai and Doumen, with a territory of more than 17,500 km^2 and total population of more than 11 million. With farmland of nearly 530,000 ha, the delta is the main production base for agricultural products such as grain, fruit, pond fish, sugarcane and peanut. According to 1986 statistics, with 16.4% farmland of the province, the delta produced grain 19.4%, fruit 40.1%, sugarcane 34%, peanut 18%, pond fish over 80% of the province's total yields. It also played an important role in the production of vegetables and raising of domestic animals.

This delta has a low, even landform and dense network of canals (or rivers). Originally, it was a gulf with many islands. Because the long period deposit of silt from the Dongjiang River, Xijinag River and Beijiang River, this gulf was changed into the present Zhujiang River Delta, and the islands became the present low mountains and hills. This delta is still expanding towards sea with 10-15 m/yr. In some places, such as the sand beach located between Jiaomen and Hongqili, the expansion rate reaches 110 m/yr.

The soil in the delta has high nutrient levels, with organic matter of 2.6-3.2%, N 0.11-0.17%, alkali hydrolysed N 90-110 ppm, total P 0.06-0.13%, quick acting P 7-13 ppm, total K 1.5-2.2% and quick acting K 34-60 ppm. Regarding climatic conditions the annual mean temperature is 21.5-22.0°C with a minimum monthly mean temperature (January) of 12.4-13.7°C and a maximum monthly mean temperature (July) of 28.1-28.8°C. The yearly accumulated value of temperature (15°C) is 6,350-6,680°C. The annual precipitation is 1,600-2,200 mm, sunshine time 1,700-2,000 hours, total radiation 105-110 Kcal./cm^2. Occasionally, there is also calamitous weather such as low temperature with continuous rain, drought, typhoon, cold dew wind, low temperature and frost.

Another convenience of the delta is it is near to Hongkong and Macao with good transportation. The commercial rate of agricultural products is higher and it is not difficult to export to earn foreign exchange. So, in many places, agriculture was diversified into an aggregated production of industry, agriculture, and commerce. The Zhujiang River Delta is presently an important base area for agricultural production in Guangdong Province. The established forest network will improve agricultural production with a better microclimate and the delta will undoubtedly play a even better role in the future.

Farmland Forest Networks

140,000 ha of farmland forest network has been established in the delta. In Xinhui, for example, all the farmland is under the protection of the forest network. The forest network established there has the following characteristics.

Forest network and water conservancy system combined - The delta is the outlet of the Zhujiang River, the elevation is very low and the underground water table high. So beside the dense natural channels, there are dense network of artificial drainage irrigation canals. With water conservancy network and road system, the forest belt can be established along them. In this way, the forest network does not occupy the farmland directly and the area of farmland shaded by the forest network can be reduced greatly.

Biodiversity of the protective forest network - Due to the good conditions of water, fertility and climate, many tree species can be used in installation of the forest network. The main tree species currently used are as follows: *Casuarina equisetifolia, Eucalyptus exserta, Eucalyptus citridora, Taxodium distichum, Taxodium ascendens, Glyptostrobus pensilis, Leucaena leucocephala* var. *suluador, Melia azedarach, Livistona chinensis* and *Bambusa eutuldoides*. The following fruit trees are common: Guava (*Psidium guajava* Linn.), lychee (*Litchi chinensis* Sonn.), longan (*Nephelium longana*), pear (*Pyrus pyrifolia* Nakai var. cultu. Nakai) and banana (*Musa basjoo*).

Multiple uses of the forest network - The composition of the species in the network system varies from place to place. Along the river banks and roads, timber species and economic species, sometimes fruit trees also are combined together to form the primary or main belt of the network. Along the main drainage/irrigation canal sides and tractor roadside, timber and fruit trees are usually planted together to form a secondary belt of the forest system. Then, along the small canals and around the ponds, only fruit trees are planted.

Fast growth of the forest network - Because of superior growth conditions, the trees planted in this delta grow very fast. It usually takes only three years from tree planting to the formation of an effective forest belt.

Benefits from the Forest Network

The farmland forest belt improves the microclimate significantly. In the range of 25 H from the belt, the wind velocity was reduced by 15-20%. In the low temperature seasons, the air and soil temperatures raised by 0.5-1.5°C compared to that outside the forest network. The daily range for both the air and soil temperatures can also be increased. The evaporation rate was reduced by 20-30%.

Damage of Cold Dew Wind -

Cold dew wind is harmful to the growth of late rice in Southern China. Under the protection of the forest network, the damage to rice can be greatly reduced. According to the comparison trial carried out in 1979 to 1981 in the rice field protected by forest network, the wilting rate of leaves (the two top leaves) was reduced by 30-60%, wilting rate of rice ear by 5.7%, fruiting rate increased by 10-20%, the weight of kilograin increased by 0.4-3.4 g, and the yield increased by 750-1,125 kg/ha.

Preventing the Damage of Late Cold Spring -

Every year, the season around March is the period of raising early seedlings or the emerging period of other spring-planted crops in southern China. If it is subjected to cold wave, the seedling death of early rice or other crops is common. If it is protected by a forest network, the seedling death can be reduced or even completely prevented. According to the investigation made in 1982, the rate of seedling death reached 43%, while the average death rate was 5.7% in the range of 10 H in the protected rice field.

Resisting Typhoons -

The effect of farmland forest networks significantly resist typhoons by reducing wind velocity. On September 8-9, 1983, for example, while typhoon 8309 was invading Doumen County with an average wind force scale of 10-11 and with a gusty scale of above 12, the average wind velocity measured at a height of 1.5 m in a farmland protected by a sparse belt with a middle-sized mesh was reduced by 32.2% compared to that in the open field. Another important effect of farmland forest system against typhoon is protecting dams from waves caused by typhoons. The farmland forest network also provides the local farmers with better housing conditions and promotes the development of tourism. Large amounts of timber and fuelwood can be obtained from thinning and regeneration of the farmland forest system. This not only supplies the farmers with timber for construction materials but also with fuelwood. In the delta, some species provide important raw materials for sideline production development. Chinese fan palm and bamboo, for example, can be used to make many articles for daily living and promotes sideline production in rural areas.

The fruit trees planted not only provide protection but yield fruit. Lile Town of Xinhui County, for example, planted 180,000 fruit trees in the protective forest system, that equals to 120 ha of pure fruit orchard. In the same county, Huancheng District has a lychee belt of 110 km, the annual yield of lychee is up to 17,500 kg.

Conclusion

The farmland forest network in the Zhujiang River Delta has its own characteristics which are determined by the special geographical location of rivers-network-plain in a subtropical zone. The ecological and economical benefits of network are significant and the forest network has been developed extensively. However, many problems still exist, some lands are not afforested, some meshes are too large, the species composition of most belt is over unitary, and so on. All these problems should be solved with further development.

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Fishpond with Mulberry - A Water-land Ecosystem

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ABSTRACT

The Zhujiang River Delta is located in the south of Guangdong Province. The conditions are suitable for planting mulberry, feeding silkworm and cultivating fish, so that silk and fish become major products. This paper introduces the conditions, characteristics, functions and prospects of this water-land ecosystem.

Introduction

The Zhujiang River Delta is located in the south of Guangdong Province. The annual solar radiation is 110 Kcal/cm and temperature 22°C. It is also located at the northern edge of the monsoon tropical zone. In some winters the minimum temperature is about 1°C, while in most years it is above 2°C and maximum temperature is 37°C in summer. The annual rainfall is about 17,000 mm mostly in summer. The relative humidity is 76-85% and the annual sunshine time is only 2,000-2,500 hours. This kind of climate is suitable for mulberry planting, sericulture and fisheries. Mulberry trees can grow throughout the year and the leaves can be used from March to November. Chinese silkworms can grow well except in January and February in which the rate of growth is slow. The most appropriate temperature of pond water for the growth of the four common domestic fishes (grass carp, variegated carp, dace, silver carp) is 25-30°C. So fish can be caught three or four times throughout the year, even five or six times for some special varieties.

Fishpond with mulberry is a successful farming system created by the people of the Zhujiang River Delta in their long production practice. Zhujiang River Delta is covered by a large area of low-lying land. In order to take advantage of this landform, the local farmers built fishponds in the low-lying area to develop fisheries. At the same time, for full use of the land resource, trees were planted around the pond. At early stages, mainly fruit trees were planted to form a system of fishponds with fruit trees. Along the development of sericulture in the delta, fruit trees planted around the fishpond were gradually replaced by mulberry trees to produce mulberry leaves for sericulture. So, a new farming system was formed, combining fishery and sericulture.

The Characteristics of the Fishpond with Mulberry

The combination of mulberry planting, sericulture and fisheries is a complex and multiple cyclic production system in which the three parts are interacted and inter-promoted. The food chain in this ecosystem is as follows: the leaves of mulberry are eaten by silkworms, the silkworm excrement is eaten by the fish, the pond mud is paved onto mulberry land. The energy and nutrient flow in the ecosystem is as shown in Fig. 1.

The material exchange and energy conversion among mulberry, silkworm and fish are affected by different environmental factors at various degrees. The growth of mulberry trees needs light, temperature, water supply and soil fertility. Mulberry is halophilic and needs sufficient sunlight with a compensation point of 1.5 Klux. When the air temperature is 25°C, the saturation point is up to 1.5 Klux. Water and soil nutrients affect directly the growth and biomass production of mulberry trees and indirectly the growth of the silkworm and the quality of cocoons because of different qualities of mulberry leaves. The factors that promote the growth of silkworms are temperature (15-30°C) and humidity (70-85%). They die at temperatures over 40°C with drought. It would be inappropriate if humidity is higher than 90%. During the period from May to

September, the high temperatures and humidity are not suitable for silkworm's growth so the local farmers take some special measures to control the unsuitable conditions.

The growth of fishes are closely related to the conditions of water temperature, dissolved oxygen and microbes. It will be unsuitable if temperature becomes lower than 5°C, or higher than 35°C. For example, the dace will be unadaptable if the temperature is lower than 7°C and die if the temperature goes lower than 3°C. African crucian carp, it will be unadaptable if temperature goes lower than 13°C and will die if it is less than 5°C. The most appropriate content of dissolved oxygen for fish is 5 mg/l. Their growth will be restrained (floating on the water surface) and the fishes will die if it goes lower than 0.2 mg/l. Generally speaking, dissolved oxygen content varies with the depth of water, the deeper the less oxygen, the shallower the more. Therefore, the tolerance of deep-layer fishes for oxygen shortage is bigger than that of shallow-layer fishes and the floating of deep-layer fishes indicates a serious shortage of oxygen. The rising content of dissolved oxygen is an important measure to increase the yield of pond fishes.

Along with the inter-promoting effect between mulberry, silkworm, and fish, a circulation of materials exits between the fishpond and its dam. In winter, local farmers dig a large amount of mud from the dry pond onto its dam, and in every summer or autumn, they bail the slurry onto its dam two to three times. As the main sources of nutrients, pond mud plays an important role on the growth of mulberry trees. Some weathered and decomposed mud may be returned to the fishponds by rainstorm erosion and then mixed with the residuals of aquatic animals or plants (algae, plankton). The bacteria release elements such as N, P, K and enrich the fertility of the mud. By this continuous circulation, the fertility of mud gets higher and higher and the supply of fertiliser to the dams is increased. The area ratio of dam to pond should be matched with the supply of fish food, which means that a sufficient supply of fish food is needed. According to experience, silkworm excrement and chrysalis and the leaves produced from 1 ha mulberry land are sufficient to feed 1 ha fishpond. Thus the ratio of fishpond to dam land is 1:1. If there is more area of fish food base or a large quantity of supplementary green fodder, the ratio could be adjusted to 3:2 or even 7:3.

On the dam, intercropping or shifting cultivation of mulberry trees with vegetable species has been practised. From November to February is the fallow period of mulberry, then vegetables are cultivated and the annual vegetable output can reach 45,000 tons/ha that mainly go to the market (two-thirds) and the rest as fodder for fish. After intensive cultivation of vegetables, the soil also gets improved and promotes the next rotation for mulberry planting.

The Advantages and Economic Benefits

The fishpond with mulberry system brings the advantages of the natural resources such as abundant solar radiation with high temperature and rich water sources into full play. Under superior conditions, the plants can grow almost throughout the year, this high biomass helps the high yielding production system.

With regard to economic benefits, there are two characteristics:

1) *Short rotation for return of money:* The system can be easily established in one year and regular economic benefits can be obtained in the first year of tree planting.
2) *High production yield:* It was recorded in Shunde County in 1978 that the mean yield of mulberry leaves was 28.5 tons/ha/yr with a maximum yield of 75 tons/ha/yr, while the yield in Taihu Lake Basin and Japan is only about 15 tons/ha/yr. With the high biomass production of mulberry trees, there is a mean yield of cocoon equal to 2,025-2,250 kg/ha/yr, while there is only 525 kg/ha/yr in Taihu Lake Basin and 535.5 kg/ha/yr. The total output of the "fishpond with mulberry" reached 8,205 Chinese Yuan (RMB)/ha/yr, i.e., four times higher than cultivation of rice and three times higher than sugarcane.

To sum up, first, fishpond with mulberry in this delta is a good productive system, which has an interaction between resources of water and land, with complex and multiple cycles, with many advantages. No other system has as many advantages as this system. It is possible to extend this system to the deltas in tropical and subtropical zones in Asia, Africa and Latin America where the population density is also very high.

Further, to increase the economic profits, it is necessary to combine some fishpond with sugarcane land. Fishpond with mulberry and fishpond with sugarcane can be shifted to each other with a rotation of several years, that will increase the yield by 15-20%. This is because the shifting cultivation can reduce the diseases and pests, and adjust the labour used in fishpond with mulberry. At the same time, a new sugarcane-livestock-fish farming system can be developed.

Although the yield of mulberry leaves and cocoon yield in the delta was higher than that in Japan and the Taihu Lake Basin, the length of silk, the rate of silk reeling and the productivity of labour were lower than in Japan and the Taihu Lake Basin. So there is high potential for increasing the improvement of culture techniques and utilisation of better varieties.

From Shifting Cultivation to Agroforestry in the Mountain Areas of Yunnan Tropics

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ABSTRACT

Besides outlining the limitations of agricultural development in mountain areas of Yunnan Province, China, shifting cultivation, agroforestry and pure crop plantation are the three major farm systems that are common in the province are relatively discussed and the periodic rotations made between trees and crops are explained.

Introduction

The Yunnan tropics include two climatic zones of northern tropics and southern subtropics, which are mainly distributed in the low-hot valleys of the Yuanjiang River, Jinshajiang, Lancangjiang and Nujiang. The total area of the tropics is about 81,000 km^2 or 21% of the total area of the province. Of which the northern tropics is about 10,000 km^2, while the southern subtropics is about 71,000 km^2. The main meteorological indexes of the northern tropics have a daily temperature not lower than 10°C throughout the year with an annual accumulative value of temperature (10°C) 7,500-8,000°C and mean temperature of January 13-15°C, while those of the southern subtropics are 285-365 days with temperatures greater or equal to 10°C with an annual cumulative value of temperature (10°C) 5,000-7,500°C, mean temperature of January 9-10°C (Academia Sinica's Editorial Committee of China's Natural Geography, 1984).

In accordance with the formula of dry index:

$$K = \frac{E}{R}$$

whereK is the dry index, R is the annual rainfall and E is equal to 0.2 times of annual cumulative value of temperature (10°C). The tropics can be divided into several regions, i.e., humid region (K = 0.5), moist region (K = 0.51-1.00), semihumid region (K = 1.01-1.50) and semi-arid region (K = 1.51-2.00). The vegetation types also vary from region to region, rainforest and mountain moss forest in the humid region, seasonal rainforest in the moist region, monsoon forest in the semi-humid region and savanna in semi-arid region. The areas covered by different regions are 5,915 km^2 of tropical humid and moist regions, 1,000 km^2 of tropical semi-humid region, 1,150 km^2 for tropical semi-arid region, 52,516 km^2 of southern subtropical humid and moist regions, 12,591 km^2 of subtropical semi-humid region and 6,733 km^2 of the southern subtropical semi-arid region.

The Yunnan tropics has favourable natural conditions for development of tropical and subtropical cash crops. The currently used farming systems in the tropical mountain areas are mainly shifting cultivation for food and cash crops for commerce. Moreover, agroforestry has been developed in certain areas although it is not the main process of agriculture in the mountain areas.

This paper discusses the development tendency of agricultural landuse systems in the mountain areas of the tropics in accordance with certain limitations of nature and society in the areas.

Limitations of Agricultural Development in Mountain Areas

Ninety-five percent of the land is covered by mountains in the Yunnan tropics. The limited land of the basins is highly developed with irrigated rice production and this is the main source of food for the area. With increasing population and develop-

Table 1. Soil and water erosion in different land use systems (Xishuangbanna, 1965-1966)

Landuse systems	Soil erosion		Water erosion	
	kg/ha/yr	Comparison in times	kg/ha/yr	Comparison in times
tropical rain forest	63	1	99	1
rubber + tea	2,241	31	206	2
pure rubber plantation	2,690	43	293	3
shifting cultivation	48,697	778	3,395	35

ment of social economics, the developmental potential of land resources are mainly dependent on the exploitation of mountain areas. However, there are many limitations that affect agricultural development. Steep slopes are the main limitation in the mountain areas. Figure 1 shows the distribution of land types classified with slopes, the area of slope of more than 15°C occupies 65.6% in northern tropics and 84.3% in the southern subtropics. The mountains where slopes are in excess of 25°C is absolutely forbidden for agriculture in the world. In the tropics, however, the agricultural activities are already being conducted in the mountains with slopes greater than 25° which causes serious ecological problem such as soil erosion. Under the influence of monsoon weather, distinct dry and rainy seasons are present. Eighty to ninety percent of rainfall is from May to October and mainly in the form of rainstorms which usually promotes soil and water erosion. Water sources are very limited in the six-month dry season which limits growth of crops if no irrigation is available. The population in the Yunnan tropics consists of 20 minorities. In the last four decades, the population doubled while forest resources reduced by 50%. Serious ecological problems such as soil and water erosion, climate deterioration, decreasing land productivity, occurred because of the over-exploitation of land resources. The low educational level has caused difficulties of technical extension and application of new technology and lack of suitable manpower to extend agricultural development.

Farming Systems in the Areas and Their Development

The tropics' agricultural economy was traditionally self-sufficient. So the agricultural products were mainly grains, only a small proportion of cash crop cultivation existed. But the agricultural structure of mountainous areas have changed a great deal owing to the doubled population and development of a commercial economy during the last 40 years. The farming systems have changed to shifting cultivation, cash crop plantation and agroforestry.

Shifting Cultivation -

Shifting cultivation is practised in many parts of the tropics and subtropics. This farming system begins with the felling of primary or secondary forest and burning the organic matter accumulated by forests to speed up mineral nutritive cycle of the ecosystem and to control weeds, diseases and pests. Then, grain crops including upland rice and maize are directly planted in the site for a short period. The land for shifting cultivation will be abandoned after two or three years' cropping due to the soil becoming poor by erosion, uncontrolled weeds and serious diseases and declined productivity. After nine or ten years' fallow, the land may be recovered and will be used again. This farming system is called "Tanghai" by Tai people in Yunnan, that is similar to Thai "Tamrai", and Burma's "Taungya". In places where population is less and land has good forest coverage, shifting cultivation makes a small gap in the immense forest. The fallow in time will recover with secondary forest, forming a somewhat stable system of forest plants. If left undisturbed the diversity of natural ecosystems and wildlife in the region will resume.

In recent years the mountain ethnic groups could not get sufficient land for shifting cultivation in this region. The fallow have been converted into the communities where *Eupatorium adenophorum*, *Imperata cylindrica*, *Musa* spp. and *Sinocalamus strictus*, etc. dominate with periodic firing. These "artificial climax communities" cover about 25% of the land in Xishuangbanna which are neither good for agriculture especially shifting cultivation nor for wildlife conservation. Therefore, the forest in Xishuangbanna has disappeared at a rate of 1.1.5% per year.

The grain products per ha have certainly increased particularly rice due to the construction of irrigation systems, use of superior varieties and input of chemical fertilisers. The region is self-sufficient in food. The local governments have adopted some policies to encourage the mountain

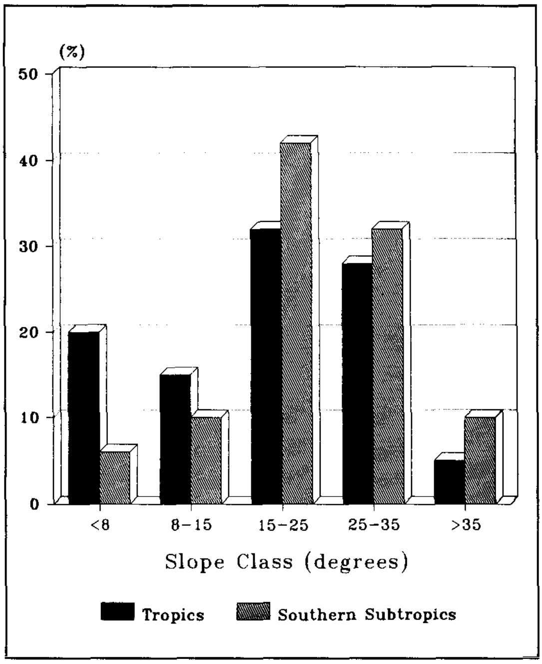

Fig. 1 Land classification of Yunnan tropics by slope

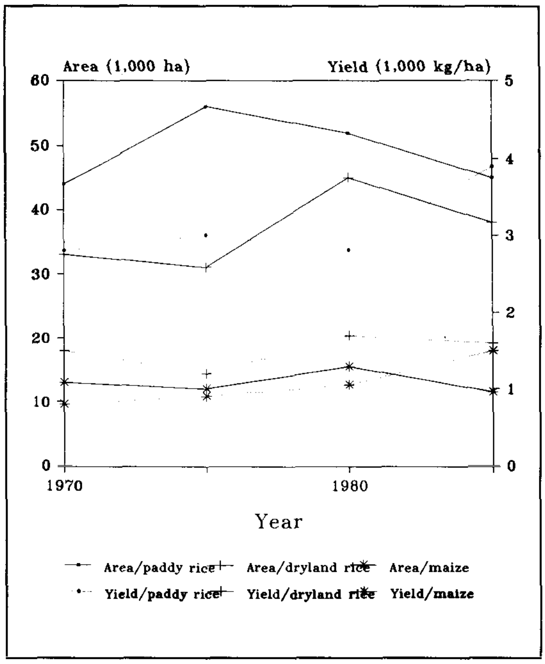

Fig. 2 The area and products of grain in Xishuangbanna region.

ethnic groups to develop cash crops (Fig. 2).

Cash Crop Plantation -

Even though a lot of tropical and subtropical plants have been introduced by the minorities for hundreds of years, only a few species have been developed for cash purposes. The development started in the middle of the 1950s with the successful introduction and cultivation of rubber trees. It is similar to that of plantations developed in South East Asia since the beginning of the century. This farming system also started the cutting down of the primary or secondary forests. The characteristics of the farming system is to establish pure plantations of single cash crops for commercial production. The rotation of this type of farming varies from 2-3 years (sugarcane) or 20-30 years (rubber trees).

The reasons for cash plantation development are several. The mountain ethnic groups could purchase some food from the local markets to supplement their needs and other needs to promote their living standard. Ecologically, the production rotation of this farming system was to avoid shifting cultivation and reduce erosion, and increase the ability to resist disasters. Politically, the development of cash crops has been encouraged and supported by the government. Cash crops in the mountain areas have been developed quickly, becoming an important pillar of the mountain ethnic economy (Fig. 3). Before 1970, the area of mountain fields was dominated by shifting cultivation. After the development of rubber and tea, the agricultural structure has caused great changes. The area of cash crop plantations surpassed that of shifting cultivation since 1985 and it will develop further.

Agroforestry Systems -

Combining agriculture and forestry (sometimes including animal husbandry), the practice of agroforestry systems forms a new landuse pattern in the mountain areas. Agroforestry systems has been practised in the mountain areas of Yunnan for many years to achieve self-sufficiency in production. For example, in the second or third year of shifting cultivation, *Cassia siamea* are seeded with upland rice, and three to five years later the trees can provide firewood. The main systems developed are described as follows:

1) *Rotation between crops and trees:* Agricultural crops and economic trees are alternatively cultivated or intercropped in this type of agroforestry system. The main planting patters are: upland rice + *Cassia siamea* (firewood); upland rice + *Gmelina arborea* (commercial timber); upland rice + rubber trees (commercial rubber); upland rice + pineapple (commercial

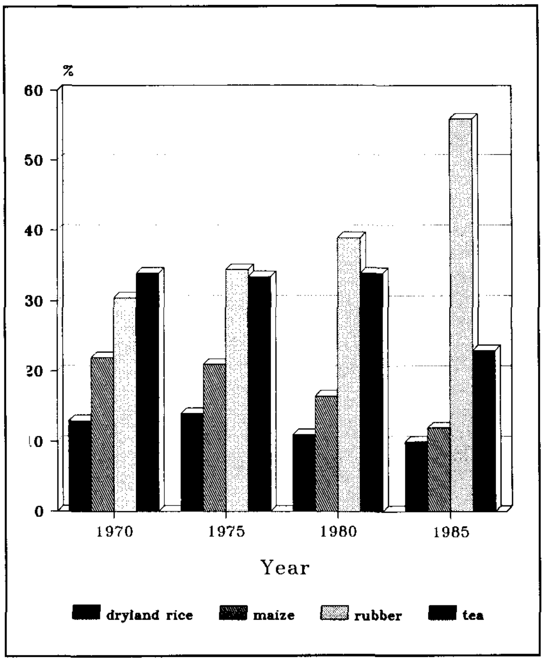

Fig. 3 The change of area percentage among shifting cultivation (upland rice, maize) and crop plantation (rubber, tea) in Xishuangbanna

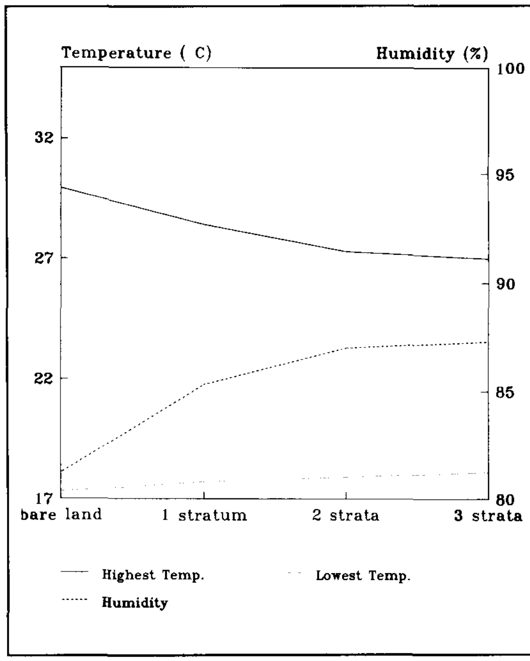

Fig. 4 The microclimate effects in different artificial cultivated communities.

fruit); maize or upland rice + *Cajanus cajan* (host of lac); or maize + *Alnus nepalensis* (commercial timber or firewood).

2) *Intercropping:* Under the tree plantations, shrubby cash crops are planted to form a multiple-storey community. Various products can be gained from the same piece of land, and the farmers could obtain income in early stage from cash crops to support trees for long profit. The major models of this planting type found in Yunnan mountain areas are as follows: Yunnan camphor + tea trees; rubber trees + tea trees; rubber trees + Chinese cardamom; alnus trees + tea trees; pomelo + coffee; or rubber trees + coffee + tea trees.

3)*Interplanting under natural forest:* Shade-tolerant economic crops are planted under natural forest after proper site preparation (cutting down some of the trees and clear the site) in this planting model. The main economic species interplanted under natural forest found in Yunnan mountain areas are tea tree, Chinese cardamom, white cardamom and cocoa.

All the agroforestry systems developed in Yunnan mountain areas are based on the rich experiences of the local farmers and research results of scientists (mainly from the Yunnan Institute of Tropical Botany, Academia Sinica). The data listed in Table 1 shows the differences of erosion control capacity existing among various farming systems in the Yunnan mountain areas. It can be seen that agroforestry systems have a high potential to conserve soil and water compared with the pure plantation and shifting cultivation. Figure 4 also shows the various microclimatic conditions in different agroforestry systems. In summary, agroforestry is a multiple purpose, highly productive and ecologically stable farming system.

Conclusion

Shifting cultivation, pure crop plantation and agroforestry are the three major types of farming systems simultaneously existing in the mountain areas of the Yunnan tropics. They have their own advantages, disadvantages and limitations. For instance, shifting cultivation should be only used in areas with low population density and relatively high forest coverage. The development of landuse systems in these areas must be determined by the natural, social and economic conditions.

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Cajanus Cajan Intercropped with Host Trees of Lacca Insects Restoring Land from Shifting Cultivation

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ABSTRACT

Shifting cultivation is common in different parts of Yunnan Province, China. Cajanus cajan was cultivated in the abandoned land along with Dalbergia sp. and other trees which are the host species for Kerria lacca, the lac producing insects. The economic benefits and ecological conditions of this agrofrestry system are discussed.

Introduction

There are over ten minorities inhibiting the tropics and subtropics of southern and southwestern Yunnan. The traditional farming system is shifting cultivation in natural forest land and it starts with slashing and burning of natural forest. Agricultural crops, especially the crops for grain production are then cultivated. The local people have to fallow the land for a period to recover the soil fertility after a rotation of four to five years of farming. The recovered land, with regenerated secondary forest, will be used again in the same way. In the continuous alternation between cultivation and fallow, the ability of regeneration of the forest gradually diminishes and there is more difficulty to recover the soil fertility. Finally the local people will abandon this piece of land for farming. With increase in population, the farming pattern has led to large-scale deforestation, soil erosion and water source decrease. During the last decade upland farmers realised the crisis situation and new farming systems such as intercropping have developed in the mountainous areas of Yunnan. The species of *Dalbergia obtusifolia*, *Dalbergia szemaoensis*, *Eriolaena spectabilis* and *Moghania macrophylla* are naturally distributed between 800-1500 m above sea level in the southern subtropical regions which are fine host species of *Kerria lacca* insects. The local farmers raise lac insects on the natural host trees and intercrop agricultural crops under the host trees as well. In this way, the farmers can get both products of lacciferidac and food at the same time. This new farming system has been practised for many years and already reached more than 6,500 ha.

Cajanus Cajan-kerria Lacca-crops Intercropping and Its Advantages

This system is a unique one since it produces agricultural products and lacciferidac which is secreted by the insects of *Kerria lacca* hosted on *Cajanus cajan*. Lacciferidac is an insulating

Table 1. Comparison of soil fertility between intercropped and open fields

Landuse systems	Depth of sampling cm	N kg/ha	P kg/ha	K kg/ha	Organic matter %	Litter kg/ha
Cajanus cajan-rice	18	7.06	42.0	142.0	2.41	1433
Rice	18	4.80	6.0	84.0	1.96	0

(Observed in October 1965 at Jinghong, Yunnan Province).

Table 2. Crop yield and output value of a farming system.

Year	Planted crops	Yields(kg)	Output values(CNY)
1954	cotton	600	2,160
1955	rice	1,800	1,800
1956	cotton	1,200	4,320
1957	rice	1,550	1,085
1958	cotton-*Cajanus cajan*	1,000/cott.	3,600
1959	soybean-*Cajanus*	235/bean	329
1960	lacciferidac	200	1,200
1961	rice	2,700	1,890
1962	cotton	1,350	4,860
1963	rice	1,700	1,190
1964	cotton-*Cajanus*	750/cott.	2,700
1965	soybean	210	294
1966	lacciferidac	434	2,604

(Place: Jinghong, Yunnan. Area: 0.89 ha).

material, tolerates high electricity and acids, anti-moist, rustproof and is easily dried. It has high elasticity, strong stick and stable chemical characteristics. It is used for electricity, hardware, plastic, rubber, mechanics, painting, printing and medicine.

Cajanus cajan is a shrub species which is a desirable host of valuable insects *Kerria lacca*. It is a multi-purpose shrub and grows fast. Its seeds contain 19.5% protein, 1.3% fats, 65.5% carbohydrates, 0.161% Ca, 0.258% P, 0.015% Fe; 100 g of seeds contain carotene 55 %g, V.B1 0.72 mg, V.B2 0.14 mg, V.C. 26 mg, amino acid 2.9 mg. Meanwhile, it has plenty of mycorrhiza in roots, therefore it is also a good feeder and green manure species. The *Cajanus cajan* based intercropping system in Lujiazhai, Jinghong County of Xinshuangbanna is a successful example of an agroforestry model which has following advantages:

Recovering and Increasing Soil Fertility -

Cajanus cajan is a nitrogen fixation tree species, increasing soil fertility. The fallen foliage can maintain and increase soil fertility also (Table 1).

Continuous Farming and Increase of Land Productivity -

The system of intercropping *Cajanus cajan* with other crops is an alternative method and for "slashing/burning-cropping-fallowing ...", and land is used successively and crop productivity increased. For instance, in Lujiazhai, Jinghong County of Yunnan Province 0.89 ha farming land was reclaimed in 1954. It was planted with cotton and rice for four years, *Cajanus cajan* in the fifth year and intercropped with cotton (Table 2). Profits were obtained from this new farming system.

Conservation of Forest Resources -

Compared with the old farming system, the newly developed intercropping system has the ability to improve environmental conditions and resulted in the increase of landuse productivity. At the same time, because it can be continuously farmed, limited land can satisfy the local farmers' requirement for agricultural production. This decreased the damage to the natural forest resources and large scale natural forests will be preserved. This conserved forest resource, in turn, provides a favourable ecological condition.

Assessment of the Ecological Conditions of a Tropical Agroforestry System

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ABSTRACT

A quantitative assessment of an ecosystem is made using the experimental data of 1983-1985 with regard to microclimatic effects, soil fertility, soil and water conservation effects, growth rate and production. The results have shown that the ecosystem of windbreak-rubber trees-cover crop (bean) is a suitable farming system for tropical China with high ecological profits.

Research Methods

Three kinds of plantations representing the general conditions of rubber tree cultivation in Guangdong and Hainan Provinces were chosen for the establishment of five meteorological stations (Table 1) including twelve microclimatic and eight rain runoff measuring sites. The items observed at the meteorological stations included air temperature, air humidity, wind velocity (these first three items were read in 1.5, 1.0, 0.5 and 0.2 m gradients synchronously from shelves built along tree trunks and from the meteorological huts), precipitation, evaporation, sunshine, ground temperature, total cloudiness, weather phenomena and soil moisture. All items except soil moisture (measured monthly) were recorded three times daily. The items observed at the microclimatic sites, which were located at Licai Agricultural Farm, Hainan Institute of Tropical Crops and Liming Agricultural Farm included those mentioned above and solar radiation and light intensity. All items were measured hourly, using shelves built along tree trunks. Other items observed included soil and water conservation effects and nutrients.

Results and Analysis

Microclimatic Features -

Total radiation amounted to 500-550 ly/day in Hainan Island. Light intensity decreased from the crowns to the floor, diminishing most rapidly at one-third depth of the crowns. The composition of the radiation differed greatly between inside and outside of the plantation. Outside the crown canopy direct radiation dominated, occupying about 65% of the open radiation, whereas within the plantation, it was diffuse. Moreover, the denser the plantation, lesser the diffuse radiation within the plantation. The albedos of various surfaces were as follows: crown canopies of the rubber plantation, secondary forest and tea plantation were 21-21, 22-23 and 17-18% respectively; grassland 17-18%; and bare land (rich in coarse sand) 28%. Albedo at the forest floor varied with the surface cover. On forest floor covered with mulch, the albedo was 29-33%. During the day, the temperature in the rubber plantation (or secondary forest) was one-half than in the open (Table 2).

The rubber plantation as well as the secondary forest and tea plantation had relatively high net radiation, reaching over 300 ly/day on clear days. Net radiation on the plantation floor was much smaller, sometimes negative (Table 2). The largest portion of energy from net radiation was used for evapotranspiration, the second largest for turbulent heat exchange and least was for soil heat flux in the rubber forest (Gao and Huang, 1986). Heat consumed in the secondary forest, the rubber-tea planation and the pure tea plantation was nearly the same as that in the pure rubber plantation. Transpiration dominated the evapotranspiration in the rubber plantation, attaining approximately 90% of the total; evaporation from the forest floor was about

Table 1. Main conditions of the meteorological stations

Station	Licai	Boating Institute	Zhongrui	Hainan Institute	Liming
Plantation type	Windbreak-rubber tree-natural vegetation; rubber strain RRim 600 planted in 1970	Windbreak-rubber tree-green manure (trailing); rubber strain Rrim 600 planted in 1981	Windbreak-rubber tree-natural vegetation inter-planted with green manure (trailing); rubber strain Rrim 600 planted in 1977	Windbreak-rubber tree-tea (inter-planted) - mulch; rubber strain Rrim 600 planted in 1977 tea planted in 1975	Windbreak-rubber tree-green manure (erect and trailing); rubber strain GT1 planted in 1980
Altitude (m above sea level)	207	94	165	70	44
Topography	Hill in southern Hainan Island	Low hill in central southern Hainan Island	Hill in central northern Hainan Island	Terrace in northeastern Hainan Island	Low hill in northern Leizhou Peninsula
Soil	Coarse sandy loam	Sandy loam	Sandy loam	Laterite	Sandy loam
Surrounding vegetation	Secondary forest	Secondary forest	Secondary forest	Bush grassland	Bush grass-slope

10%. The turbulent heat flux in the open was higher than in the rubber plantation and secondary forest, and it was slightly higher above the tea plantation and secondary forest than that of the rubber plantation or rubber-tea plantation. The turbulent heat exchange inside the stands was very low, sometimes even negative because of temperature inversions in the earth air layer. Soil heat flux in the open was higher than that in plantations or forest stands. Soil heat flux in the rubber plantation and rubber-tea plantation was equivalent to the secondary forest and the tea plantation respectively.

The planation with a denser canopy had a lower temperature during the hot season and higher temperature during the cold season, whereas the plantation with a less dense canopy was hotter during the hot season and colder during the cold season. Temperature effects of rubber plantations are quite similar to that of broadleaved forests. The annual mean temperature of the plantations was close to that in the open, but the seasonal variations and maximum and minimum showed great differences. In autumn, the temperatures in the plantations were 0.3-0.5°C lower than in the open, but 0.1-0.3°C higher than in the secondary forest. Extreme temperatures, especially the annual minimum were lower in the plantations than in the open. Annual and diurnal variations of the ground temperature (0 cm) were generally greater than the air temperature. With increasing depth, however, the variation of ground temperature diminished, especially below 20 cm. The various strata temperatures observed at the plantations were lower than in the open, but higher than in the secondary forest. Moreover, the temperature of the ground covered with green manure was comparatively lower, e.g., its annual mean temperature and hottest month mean temperature were 1.5°C and 3°C lower than in the open respectively.

Annual rainfall was equivalent to the annual evaporation in the open field, whereas it was about 2:1 in the plantations.

Average annual wind velocity in the plantation attained only 0.3-0.6 m/s - about 13-32% of the wind speed in the open due to the protection of windbreaks.

Soil and Water Conservation -

Among all plantations observed, the Liming Estate, where the soil was covered with thriving leguminous green manure and roots of the rubber trees with mulch, had the best effect on soil and water conservation (Table 3). The rain runoff and the amount of soil loss at the Liming Estate was only 7.1 and 16% respectively of that of the open. Hainan Institute established a newly cultivated plantation of rubber trees interplanted with tea in 1982. Here, soil erosion was highest observed. Nevertheless, the runoff coefficient at the Hainan Institute site was still smaller than in the open. The frequency of runoff in the plantations was less and the minimum rainfall which caused runoff was larger compared to the open, indicating that only relatively heavy rainfall might cause runoff in the plantations. Soil moisture content in all plantations observed were higher than in the open. For ex-

Table 2. Components of net radiation in various active strata on clear days

Station	Forest type	Global radiation	Reflected radiation	Effective radiation	Net radiation
		(ly/day)			
Licai	Rubber forest	570.3	130.9	63.1	376.3
	Rubber forest floor	66.4	27.8	64.0	25.4
	Secondary forest	576.8	143.7	59.3	364.8
	Secondary forest floor	45.8	9.7	49.3	13.2
	Open field (bare land)	544.0	150.4	116.8	276.8
Hainan Institute	Rubber-tree plantation	463.8	92.7	63.0	308.1
	Rubber-tree plantation floor	74.8	36.7	52.6	14.5
	Tea forest	468.5	82.2	66.5	319.8
	Open field	455.8	82.5	117.7	265.6

Data measured on 14-15 April 1984 in Licai, 21-22 March 1983 and 20-21 April 1984 in Hainan Institute. All the data are the means of the observations.

ample, the 0-20 cm soil layer at Liming was about 30% higher in moisture than the grassland, and at Licai 15% higher than in the secondary forest.

In an assay made in 1984, the organic matter content of the soil ranged from 2.1-3.8% in most plantations observed. The organic matter, nitrogen and phosphorous contents in the soil of the plantations were higher but potassium, calcium and magnesium were lower than in the open. However, by planting grass and using green manure in the plantations, the soil fertility greatly increased.

A Synthetic Assessment of the Ecological Benefit

In the following portion of the paper, a synthetic quantitative assessment of the ecological benefit of artificial groups of several major types of rubber plantations in the tropical areas of China is made using the multi-grade fuzzy assessment. Soil fertility, soil and water conservation and rubber production or diameter increment of rubber trees were selected as factors for assessment.

Introduction to Fuzzy Multi-grade Synthetic Assessment -

A synthetic assessment is made by using the principle of fuzzy relations after considering the effects of all the factors on the object assessed.

1) *A primary model of the fuzzy synthetic assessment:* Suppose the set of the attended factors will be X and the set of assessing will be Y. Then, they are:

$$X = [x_1, x_2, \ldots\ldots, x_n]$$

$$Y = [y_1, y_2, \ldots\ldots, y_n]$$

2) Let fuzzy relation from x to y be $\underset{\sim}{R}$. Then, we get

$$\underset{\sim}{R} : X \times Y$$

$\underset{\sim}{R}$ can be represented by matrix n x m in closed interval [0, 1] as following:

$$\begin{array}{c|c} \underset{\sim}{R} & y_1\ y_2\ \ldots\ y_m \\ \hline x_1 & r_{11}\ r_{12}\ \ldots\ r_{1m} \\ x_2 & r_{21}\ r_{22}\ \ldots\ r_{2m} \\ \cdot & \\ \cdot & \ldots\ldots\ldots\ldots \\ \cdot & \\ x_n & r_{n1}\ r_{n2}\ \ldots\ r_{nm} \end{array} \qquad (1)$$

The assignment of weight of the attended factors can be presented by a fuzzy subset $\underset{\sim}{A}$~, the membership of x_j in relation to $\underset{\sim}{A}$~, the membership %$_x(x_i)$ is called the weight of the attended factor x_i; best let

$$\sum_{i-1}^{n} (x_i) = 1$$

so that $\underset{\sim}{A}$ is normalised and $\{\underset{\sim}{A}(x_i)\}$ is the assignment of the weight of attended point.

If the assessing matrix of single factor R and the assignment of weight of the attended factor $\underset{\sim}{A}$ are given, then the synthetic assessment is

$$\underset{\sim}{B} = \underset{\sim}{A} \bullet \underset{\sim}{R} \qquad (2)$$

Table 3. Soil and water conservation conditions of the plantations

Item	Liming		Hainan Institute	
	Rubber plantation	Open field (grass slope)	Rubber-tree plantation	Open field (grassland)
Amount of rain runoff (m)	4.99	69.45	10.16	15.09
Depth of runoff (mm)	16.63	231.5	50.78	75.45
Runoff coefficient	0.011	0.15	0.048	0.071
Amount of soil loss (kg/ha)	42.6	263.9	966.5	169.4
Modules of erosion	23.65	146.66		
Number of rainfalls	52	52	29	29
Number of rain runoffs	33	42	24	26
Soil moisture content 0-20 cm (%)	16.65	12.73	33.48	32.02

Data collected from January - December 1983 in Liming, and from September 1983 to January 1984 in Hainan Institute.
Runoff area measured: Liming - 300m2, Hainan Institute - 200 m2.
All the data listed here are the means of the observed figures.

3) *The fuzzy multi-grade synthetic assessment:* In a complex system, generally there are many factors to be considered and the factors may belong to different grades. Now, if using a primary model of synthetic assessment, it is difficult to make a fine assignment of weight. Even if we can determine the weight because

$$\sum_{i=1}^{n} a_i = 1$$

should be met, so that the weight a_i from each factor must be very small another value of synthetic assessment will be also very small. Thus, the results will be meaningless.

According to some attributes, we can divide the set of factors into several types to evaluate each type by using a primary model of assessment, then make further synthetic assessment of a higher grade between all types according to the results of each type of the assessment. The model formula is:

$$\underset{\sim}{R}^* = \begin{pmatrix} \underset{\sim}{B_1} \\ \underset{\sim}{B_2} \\ \bullet \\ \bullet \\ \bullet \\ \underset{\sim}{B_n} \end{pmatrix} = (b_{ij})_{n \times m} \qquad (3)$$

where $\underset{\sim}{B}_1, \underset{\sim}{B}_2, ..., \underset{\sim}{B}_n$ are the results of the synthetic assessment using the primary model.

Suppose $\underset{\sim}{A}_1$ is the first grade assignment of weight, then we can get

$$\underset{\sim}{B}^* = \underset{\sim}{A}^* \bullet \underset{\sim}{R}^*$$

$\underset{\sim}{B}^*$ is the result of second grade synthetic assessment and also is the result of synthetically assessing all factors in X.

The synthetic assessment model II can be written as

$$\underset{\sim}{B}^* = \underset{\sim}{A}^* \bullet \underset{\sim}{R}^* = \underset{\sim}{A}^* \bullet \begin{pmatrix} A_1 R_1 \\ A_2 R_2 \\ \bullet\bullet \ \bullet\bullet \\ A_n R_n \end{pmatrix} \qquad (4)$$

Test Plots -

There are three kinds of artificial ecological groups of rubber trees in Guangdong reclamation area: 1) The windbreak-rubber tree-cover crop (bean); 2) The windbreak-rubber tree-perennial crop (such as tea or coffee); and 3) The windbreak-rubber tree-natural vegetation mulch (such as the bush and herb).

According to the characteristics of the natural environment three observation stations were established (Table 4). Microclimate and rain runoff observation stations were established in each test plot, and in the natural cover areas which were chosen for reference, fertility and growth observation plots were marked.

Items Observed -

(1)*Water and soil conservation:* Items observed mainly include the run-off, shifting of silt, depth of runoff, minimum amount of precipitation producing runoff, maximum amount of

Table 4. Main conditions of stations

Station	Liming	Hainan Institute	Licai
Latitude Longitude	21°23'N 110° 13'N	19°28'N 110°26'E	18°24'N 109°19'E
Topography	Low hill in northern Leizhou Peninsula	Terrace in north-estern Hainan Island	Hill in southern Hainan Island
Soil	Sandy loam	Laterite	Coarse sandy loam
Type of plantation	Windbreak-rubber trees-green manure (erect and trailing) rubber strain GT1 planted in 1980	Windbreak-rubber trees-tea (inter-planted) - mulch; rubber strain Rrim 600 planted in 1975, tea planted in 1977	Windbreak-rubber trees-natural vegetation; rubber strain Rrim 600 planted in 1970
Vegetation	Bush grass slope	Bush grassland	Secondary forest

precipitation which did not produce runoff, frequency of runoff, amount of precipitation absorbed by tree crowns and soil moisture. (2) *Soil fertility:* We mainly measured and recorded organic matter, N, P, K, minor elements content and amount of duff back to soil. (3) *Observations in the microclimatic sites:* The conventional items observed in the microclimatic sites included air temperature, air humidity, precipitation (in open, intercepted by tree trunk and by crown canopy), evaporation, sunshine, wind velocity, ground temperature. Besides the large or small shelter, gradient observations (height: 0.2, 0.5, 1.0, 1.5 m) were made. Solar radiation (including direct, diffused and reflected radiation), hourly and daily amounts of radiation, gradient observation of temperature, humidity and wind velocity measured at 11 different heights are also performed. (4) *Others:* The other items included phenological phase, growth rate, rubber production, leaf wither and fall, etc.

The Results and Analysis -

In this paper we have considered three elements of soil fertility, water and soil conservation and rate of rubber production (girth increase) for assessing different types of ecological profits. The rubber production is comprehensively affected by environmental and climatic conditions.

The Primary Assessment of Single Factor -
The soil fertility -

There are many factors that can affect soil fertility. In this article, we have chosen the organic matter, N, P, K and minor elements (Ca, Mg, etc.) for the assessment of soil fertility. Thus, the set of assessment factors are:

$$X = [x_1, x_2, x_3, x_4, x_5, x_6]$$

According to the different effects of every factor, assignment of weight is given by the following:

$$A = [0.40, 0.20, 0.15, 0.05, 0.05]$$

The results fall into three classes as follows:

$$Y = [\text{EXCELLENT, GOOD, BAD}]$$

According to the test data, each soil factor in the three test plots will be graded through giving scores. The criteria of grade are shown in Table 5.

According to the formula (1), the fuzzy relationships are established as follows:

$$\underset{\sim}{R}_{lim} = \begin{pmatrix} 5\,0\,0 \\ 2\,0\,0 \\ 3\,0\,0 \\ 0\,4\,0 \\ 5\,0\,0 \\ 0\,2\,0 \end{pmatrix} \qquad \underset{\sim}{R}_{hai} = \begin{pmatrix} 0\,5\,0 \\ 0\,5\,0 \\ 0\,3\,0 \\ 0\,0\,1 \\ 5\,0\,0 \\ 0\,4\,0 \end{pmatrix}$$

$$\underset{\sim}{R}_{lic} = \begin{pmatrix} 5\,0\,0 \\ 0\,0\,2 \\ 0\,0\,1 \\ 0\,0\,5 \\ 0\,0\,5 \\ 0\,0\,4 \end{pmatrix}$$

lim: Liming Farm
hai: Hainan Institute
lic: Licai Farm

From formula (2), the results of the primary synthetic assessment are:

From the above-mentioned results of assessment, we see that the fertility on Liming Farm is the best one of the three kinds of fertility factors. It is the windbreak-rubber plantation with bean as cover crop.

Table 5. The criteria of scores

Item	First grade assessing factors	Excellent					Good					Bad				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Soil fertility	Organic matter	20-25	26-30	31-35	36-40	>40	0-1	2-5	6-10	11-15	16-19	1-5	6-10	11-15	16-19	>20
	N	20-25	26-30	31-35	36-40	>40	0-1	2-5	6-10	11-15	16-19	1-5	6-10	11-15	16-19	>20
	P	20-25	26-30	31-35	36-40	>40	0-1	2-5	6-10	11-15	16-19	1-5	6-10	11-15	16-19	>20
	K	20-25	26-30	31-35	36-40	>40	0-1	2-5	6-10	11-15	16-19	1-5	6-10	11-15	16-19	>20
	Ca	20-25	26-30	31-35	36-40	>40	0-1	2-5	6-10	11-15	16-19	1-5	6-10	11-15	16-19	>20
	Mg	20-25	26-30	31-35	36-40	>40	0-1	2-5	6-10	11-15	16-19	1-5	6-10	11-15	16-19	>20
Soil and water conser-vation	Runoff coef	25-30	31-35	36-40	41-45	>45	0-5	6-10	11-15	16-20	21-25	1-5	6-10	11-15	16-20	>20
	Runoff freq	25-30	31-35	36-40	41-45	>45	0-5	6-10	11-15	16-20	21-25	1-5	6-10	11-15	16-20	>20
	Soil loss	25-30	31-35	36-40	41-45	>45	0-5	6-10	11-15	16-20	21-25	1-5	6-10	11-15	16-20	>20
	Soil moist	11-13	14-16	17-19	20-22	>22	0-2	3-5	6-8	9-11	>11	1-3	4-6	7-9	10-12	>12
Rubber growth	Yield growth	11-15	16-20	21-25	26-30	>30	0-2	3-5	6-8	9-11	>11	0-2	3-5	6-8	9-11	>11
		11-15	16-20	21-25	26-30	>30	0-2	3-5	6-8	9-11	>11	0-2	3-5	6-8	9-11	>11

$$\underset{\sim lim}{B} = (0.73, 0.27, 0)$$

$$\underset{\sim hai}{B} = (0.08, 0.67, 0.25)$$

$$\underset{\sim lic}{B} = (0.67, 0, 0.33)$$

The water and soil conservation -

By considering four elements (rain runoff coefficient, frequency of rain runoff, amount of soil loss and soil moisture), we can assess the overall status of soil loss. By using the former methods, the scores for every grade must be fixed first. The criteria of scores are listed in Table 5. Then, we will establish the relation of $\underset{\sim}{R}$ as follows:

$$\underset{\sim lim}{R} = \begin{pmatrix} 5&0&0 \\ 5&0&0 \\ 5&0&0 \\ 5&0&0 \end{pmatrix} \quad \underset{\sim hai}{R} = \begin{pmatrix} 0&0&5 \\ 0&1&0 \\ 0&0&5 \\ 0&3&0 \end{pmatrix} \quad \underset{\sim lic}{R} = \begin{pmatrix} 0&0&5 \\ 0&0&5 \\ 0&0&5 \\ 5&0&0 \end{pmatrix}$$

The set of weight assignment is:

$$\underset{\sim}{A} = [0.15, 0.05, 0.30, 0.50]$$

The result of the synthetic assessment of B are respectively:

$$\underset{\sim lim}{B} = (1,0,0)$$

$$\underset{\sim hai}{B} = (0,0.63, 0.37)$$

$$\underset{\sim lic}{B} = (0.63, 0, 0.37)$$

The results show that the soil and water conservation in Liming Farm was the best one, the second Licai Farm, and Hainan Institute was the worst.

The second grade synthetic assessment - On the basis of the results of primary synthetic assessments of the soil fertility, water and soil conservation, the second grade assessment was carried out which included soil fertility, water and soil loss, rubber growth or production.

The method and steps are the same as the primary assessment. The set of comment of the second grade synthetic assessment still is:

$$Y^* = [y_1, y_2, y_3] = [\text{EXCELLENT, GOOD BAD}]$$

Given the assignment of weights A^*, then:

$$A^* = [0.3, 0.2, 0.5]$$

The rubber growth rate or the production, here, means the increase of the girth or yield of dry rubber per mu (1/15 ha). Because only one index related to rubber growth or yield is selected, the primary model is not established and the second grade synthetic assessment can be directly done.

The relations $\underset{\sim}{R}^*$ of the second grade synthetic assessment is established as follows:

$$\underset{\sim lim}{R^*} = \begin{pmatrix} 0.73 & 0{,}27 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$

$$\underset{\sim hai}{R^*} = \begin{pmatrix} 0.08 & 0.67 & 0.25 \\ 0 & 0.63 & 0.37 \\ 0 & 1 & 0 \end{pmatrix}$$

$$\underset{\sim}{R}^*_{lic} = \begin{pmatrix} 0.67 & 0 & 0.33 \\ 0.63 & 0 & 0.37 \\ 1 & 0 & 0 \end{pmatrix}$$

where member of b_{31} in the $\underset{\sim}{R}^*_{lim}$, member of b_{32} in the $\underset{\sim}{R}^*_{hai}$ and member of b_{31} in the $\underset{\sim}{R}^*_{lic}$ all are the scores of growth rate or yield (because of tapping rubber trees in Liming Farm and Hainan Farm, where the numbers refer to the girth increase and the number in Licai Farm are the yield of dry-rubber).

The second grade synthetic assessment are made by using formula (4). The results are:

$$\underset{\sim}{B}^*_{lim} = (0.65, 0.35, 0)$$

$$\underset{\sim}{B}^*_{hai} = (0.10, 0.60, 0.30)$$

$$\underset{\sim}{B}^*_{lic} = (0.63, 0, 0.37)$$

The abovementioned results clearly show that windbreak-rubber tree-cover crop (bean) in Liming Farm is the best artificial ecological group. Ecological benefit of the windbreak-rubber tree-natural vegetation in Licai Farm ranks second. However, the windbreak-rubber tree-perennial crop mulch is the worst of the three kinds of artificial ecological groups.

Conclusion

The multi-layer eco-structure composed of the windbreak-rubber tree-cover crop (bean) provides the best water and soil conservation so that the fertility increased, and production level was raised. It is a pattern that merits further growth of rubber in Guangdong. For the eco-structure of windbreak-rubber tree-natural vegetation, which is established on an area of opening up secondary forest in south Hainan Island, its ecological function is lower than the secondary forest. Because of the fine natural conditions here, field management and fertilising may be neglected. People may also forget to prevent water and soil loss and the result may be disastrous. The eco-structure of windbreak-rubber tree-tea or grassland is in the eastern part of Hainan Island. The intensive management of rubber trees are used to achieve the growth conditions. However, at the early stage of planting tea trees, because of frequent farming, it is possible to cause water and soil loss. Therefore, a good deal of attention must be paid in these areas. The multi-grade synthetic assessment is a quantitative and simple mathematical method. This is only the first tentative application of the method in assessing ecological benefits, but the results described here are satisfactory. It is believed that this method will be extensively applied and improved.

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Intercropping in Rubber Plantation and Its Economic Benefit

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ABSTRACT

Rubber (Hevea brasiliensis) is an economic tree species widely planted in southern China. Establishment and management of rubber plantation needs large investment (6,000 Chinese Yuan (RMB)/ha) and there is no return for eight years. In order to make full use of the land, a large scale intercropping experiment in rubber was carried out. This paper introduces briefly several successful intercropping models in rubber plantation.

Types of Intercropping

Rubber-Food Crops -

Different crops of food, fodder and vegetables are cultivated in rubber plantations. The most common crops are sweet potatoes, maize, sorghum, cassava and peanuts, etc. All these crops are harvested once a year, some even twice. Although their economic benefits show quickly, they are of low value as they have to be planted and sown each year which increases the costs. This type of intercropping is mainly practised by villagers.

Rubber-Economic Plants -

Economic plants such as tea, coffee, pepper, sugarcane, lemon grass and Sisal hemp are interplanted with rubber trees simultaneously and usually harvested for the first time beginning the third year. The harvests last for more than five years with great economic benefits. This type of intercropping is now prevalent in south China.

Rubber-Fruit Trees -

According to the experiments carried out, it was not practical to interplant perennial fruit trees under rubber because of the influence of shade. But planting shrubs or herbs was a promising practice, especially banana and pineapple. Other fruit plants are interplanted in rubber on experimental basis.

Rubber-Traditional Chinese Medicinal Plants -

Southern China abounds in traditional Chinese medicinal plants but few can thrive under rubber trees. It is reported that three species have been selected - *Alpinia oxyphylla*, *Amomum longiligulare* and *Morinda officinalis*. It is necessary to test other medicinal plants in combination with rubber.

Intercropping Models and Their Economic Benefits

In order to obtain more food and fodder many crops such as sweet potatoes, maize, cassava and peanut were cultivated before the canopy closed. The land was prepared carefully through plowing, trench digging, ridging and fertiliser applying which increased the production costs. The total cost was 750-1,000 Chinese Yuan (RMB)/ha and the gross income was 1,200-1,500 Chinese Yuan (RMB)/ha, that gave only around 500 Chinese Yuan (RMB)/ha of net profit. Due to its high cost and low profit, this type of intercropping was carried out in rural areas where a large labour force is available. Years of practice show that the best model of intercropping is rubber-maize-sweet potato/peanut or rubber-*Tephrosia candida*/Lucerne.

Rubber-tea intercropping - Rubber and tea trees are usually planted at the same time, but either of them can be planted one or two years after the other. Because tea plant can tolerate some shade between rows of rubber trees and can coexist harmoniously for a long time. Rubber trees were spaced at 2 x 12 or 2 x 15 m whereas intercropping spacing for tea trees was 0.4 x 0.6 or 0.4 x 0.5 x 1.0 m. In addition, 1.5-2 m of space along each side of rubber trees was kept for the convenience of tending, fertilising and rubber tapping. Tea was collected three years after planting, and its yield increased gradually year after year, until its peak at six or seven years. Tending the tea tree intercropped with rubber accelerated the growth and prolonged the life of rubber trees. The tapping began one or two years earlier and lasted for about 20 years, five or six years longer than that of monoculture plantation.

Rubber-coffee intercropping - Coffee can be interplanted between rubber trees before or after rubber tapping with a spacing of 1.5 x 1.5 or 1 x 2 m. The best area ratio between coffee and rubber is 30% and 70%. Three years after planting, coffee was harvested and the yield increased gradually for three or four years until it reached its maximum. Nanhua Farm of Guangdong Province planted 367 ha of coffee in rubber trees and 149 ha of such intercropping went into production for coffee and rubber in 1986. The mean output of coffee for the first year was 247.5 kg/ha, which amounted to 2,970 Chinese Yuan (RMB)/ha, the mean output for rubber was 364.5 kg/ha, which amounted to 2,187 Chinese Yuan (RMB)/ha.

Rubber-coffee-pineapple intercropping - These three plants are usually planted simultaneously. Rubber was spaced at 2 x 8 or 2 x 12 m and intercropping spacings for coffee and pineapple were 1.5 x 1.5 or 1.5 x 2 m and 0.5 x 0.6 or 0.4 x 0.5 m respectively. Pineapple was harvested from the second year and lasted for five years with a mean income of 1,000-2,000 Chinese Yuan (RMB)/ha. Four and seven years after planting, the coffee and rubber could be harvested and tapped respectively. Such intercropping was planted in Nanhua Farm in 1986, and pineapple was harvested in June, 1988 with an income over 2,000 Chinese Yuan (RMB)/ha. The coffee tree was 1.2 m in height and the rubber reached a height of 4 m and a diameter of 3 cm at breast height, which were 6-10% higher than those of monorubber plantations. At the present time, the intercropping of the three plants has formed a profitable system.

Rubber-sugarcane intercropping - Sugarcanes usually planted between rows of rubber trees with a spacing of 0.3 x 0.8 m. Once planted, the sugarcane can be harvested three or four times. Farms under Zhangjiang Reclamation Bureau intercropped 844 ha sugarcane in rubber in 1986. The average sugarcane yield was 23 t/ha, valued at 1,598 Chinese Yuan (RMB)/ha. A farmer in Hong Xing Farm planted 0.85 ha sugarcane under rubber trees in 1986, and harvested 30 tons of sugarcane in the same year and gained a net income of 1,792 Chinese Yuan (RMB). At the same time, sugarcane intercropping enhanced rubber growth.

Rubber-lemongrass intercropping - Lemongrass plant cannot grow well under shade. It was planted at the same time as rubber trees with a spacing of 0.8 x 1.0 or 0.5 x 0.7 m between rows of rubber trees; and harvested five or six months after planting, then once every four or five months. Each time 10-15 tons/ha of fresh leaves were collected and turned into 100-150 kg citronella oil, which was worth 7,600-11,400 Chinese Yuan (RMB)/ha. After deducting costs, the income was 2,600-6,400 Chinese Yuan (RMB)/ha. One hundred and forty-three ha were intercropped in Danxing County of Hainan Province in 1987. Twelve tons/ha citronella oil was refined from lemongrass harvested from the intercropping and $100,000 was earned by exporting the oil in the same year. If coffee is added into the intercropping with a spacing of 1.5 x 1.5 or 1.0 x 2.0 m, the income may be much higher due to the coffee's vertical leaf structure and consecutive output. Furthermore, lemongrass has a developed lateral root system which makes it grow fast and cover the land completely, three or four months after planting. It is also good for soil and water conservation.

Rubber-Traditional Chinese Medicine Models

- Rubber-*Alpinia oxyphylla* -

This intercropping was done in mountain and hilly areas where the soil is quite fertile. Mountain slopes were terraced and prepared carefully, then rubber were planted with a spacing 2 x 7 or 2 x 8 m. Container seedlings or seeds of *Alpinia oxyphylla* was intercropped with rubber trees when they were closed. Three years later, about 400 g of seeds were collected from each stock for the first harvest year. Afterwards, 400-500 kg/ha of the seeds were harvested and 3,000-4,000 Chinese Yuan (RMB)/ha was obtained each year.

Rubber-*Morinda officinalis* - The environmental condition needed to grow *M. officinalis* is similar to that of *Alpinia oxyphylla*. Cuttings of *M. officinalis* were planted under rubber trees in three to five rows with a spacing of 0.5 x 0.8 m. They were harvested five years after planting and the yield was 250-300 kg/ha worth 10,000-15,000 Chinese Yuan (RMB)/ha. After deducting costs, the income exceeded 5,000 Chinese Yuan (RMB)/ha.

Rubber-*Amomum longiligulare* - It is reported that the best time to intercrop *A. longiligulare* under rubber trees is three or four years after rubber planting. The spacing adopted was 0.6 x 0.7 m and *A. longiligulare* took 50% of the total area. It began fruiting three or four years after intercropping, almost when rubber trees were ready for tapping. Every year, the output of *Amomum longiligulare* was 80-120 kg/ha, worth 2,400-3,600 Chinese Yuan (RMB)/ha, the output of rubber was 600-750 kg/ha, valued 3,600-4,500 Chinese Yuan (RMB)/ha. The total income from these were 6,000-8,000 Chinese Yuan (RMB)/ha.

Rubber-Fruit Tree Models -

There are many fruit plants in southern China and some very famous. Experiments have shown that pineapple and banana are promising for intercropping with rubber, other fruit trees need to be tested further.

Rubber-pineapple - Pineapple is normally intercropped and harvested before rubber trees become closed completely. Rubber was spaced 2 x 8 or 2.5 x 10 m, whereas intercropping spacing for pineapple was 0.5 x 0.7 x 1.0 or 0.4 x 0.5 x 0.8 m and in this intercropping system, rubber and pineapple each took half of the total area. Some pineapples were harvested from the second year after planting. The yield increased gradually year after year and reached its peak at the age of four to five years. Yuhao Farm of Zhangjiang intercropped 265 ha pineapple with rubber and harvested a mean of 8.5 tons/ha which was worth 3,390 Chinese Yuan (RMB)/ha.

Rubber-banana - Rubber and banana were usually planted at the same time. Spacing for the former was 2 x 8 or 2 x 10 m, the latter 2 x 2 m. Tending, irrigating and fertilising were carried out to promote their growth. Hongsing Farm planted banana between rows of rubber trees in 1985 and harvested them the next year. The average output was 7,500 kg/ha, worth 4,500 Chinese Yuan (RMB)/ha. The highest output was 11,350 kg/ha, worth 6,810 Chinese Yuan (RMB)/ha. This intercropping is now very popular in Southern China for its high economic benefit. However, the important thing in establishing this intercropping is to select fertile soil. Otherwise, the result is not as good as expected.

Conclusion

Various intercropping of rubber and cash crops have been practised in Southern China. Most of them are carried out by farmers themselves. The various models of intercropping mentioned above are very successful. Especially rubber-coffee-pineapple, rubber-tea, rubber-lemongrass, and rubber-fruit. These intercropping techniques not only accelerated rubber growth and prolong the rubber production period, but also bring high economic, ecological and social benefits in a short time. Thus, they should be developed on a large scale. However, due to the lack of systematic research and limited information, it is necessary to conduct systematic research on intercropping and other agroforestry techniques to promote the development of agroforestry in southern China.

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Study on the Intercropping in Rubber Plantations in China

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ABSTRACT

A mathematical model, with many formulae, for intercropping rubber with pepper has been built. The ecological effects and economic benefits are outlined.

Introduction

Large scale cultivation of rubber trees was started in 1950 and to increase yield of rubber per unit area many efforts had been made. One of them is to study the optimum planting spacings. During 40 years the spacings were changed considerably. Table 1 shows that the spacing in the rows changed from 5 m to 2 m and the row spacing from 5 m to 10 m. Hence, there were quite large spaces between rows in the early years after planting and after adopting the spacing system 3 x 8 or 2 x 10 m. Weeds grew and spread in these spaces even though some leguminous cover plants had been planted already. Weeds are harmful to rubber tree growth and also require labour to weed. Therefore, the planting spacings should be selected properly to promote optimum production. Intercropping provides extra food or additional income.

Potential Productivity Of Rubber Plantation Of China

According to our investigation, 50% of land on a rubber plantation with planting spacing of 3 x 8 m can be used for intercropping in the first three or four years, and 60% in the first five or six years while planted with a spacing of 2 x 10 m. Hence for the plantation with spacing of 3 x 8 m, the ratio of the land that can be used for intercropping in a rotation of management (30 years) can be calculated as follows:

$$Is_1 = \frac{3.5\times0.5}{30\times1} = 5.83\%$$

while for the plantations with planting spacing of 2 x 10 m:

$$Is_2 = \frac{5.5\times0.6}{30\times1} = 11\%$$

The total area for rubber plantation of China in 1985 was 516,380 ha, hence we can estimate the area of land for intercropping:

A1 = 516, 380 x 5.83% = 30,105 (ha)

or

A2 = 516,380 x 11% = 56,802 (ha)

A Mathematical Model for Growth of Plants in an Intercropped Rubber Plantation

Since rubber tree is tall and takes usually six to eight years before it is tapped, the plant chosen for intercropping should bring good economic results in the first several years. This plant should also be shade tolerant. The authors suggest that pepper or a medicinal plant (such as *Morinda officinalis*) is the ideal plant for intercropping.

Assuming soil with given fertility and a favourable climatic environmental condition, the growing rate of the given plant can be expressed by the following equation:

$$\frac{dx}{dt} = Ax\,(1 - \frac{X}{B}) \qquad \textbf{(1)}$$

Table 1. Planting densities of rubber plantations in China at different periods.

Period of time	Spacing (m)	Density (trees/ha)
Beginning and middle 1950s	5 x 5	400
Later 1950s to middle 1960s	4 x 6	417
Later 1960s to later 1970s	3 x 8	417
Beginning 1980s to present	2 x 10	500

wherex is the biomass in a given area at t, dx/dt is the growing rate, A is the proportional constant depending on the feature of this specific plant and some environmental conditions, and B is the maximum potential biomass in this given area.

After integration of equation (1), we find:

$$x = B(1 + \frac{B-x_0}{x_0} e^{-At})^{-1} \qquad (2)$$

wherex_0 is the initial biomass, and equation is the famous logistic curve. From equation (2) it is found that x = xo as t = 0 and x = B as t .

For a monocultural rubber plantation (without intercropping):

$$\frac{dx_1}{dt} = A_1X_1 (1- \frac{x_1}{B_1})$$

and for a monocultural pepper plantation:

$$\frac{dx_2}{dt} = A_2X_2 (1 - \frac{x_2}{B_2})$$

Now let us consider the situation of a rubber plantation intercropped with pepper. Owing to the fact that rubber is a tall tree and pepper is a short plant, we may assume that the growing of pepper has no (or very little) influence on the growing of rubber. Hence the growing state of rubber can still be described by

$$\frac{dx_1}{dt} + A_1x_1 (1 - \frac{x_1}{B_1})$$

But as the rubber becomes taller, rubber will influence the growth of pepper more and more, hence the equation for describing the growing state of pepper should be modified as:

$$\frac{dx_2}{dt} = A_2X_2 (1 - \frac{x_2+x_1}{B})$$

Since the maximum biomasses B_1 and B_2 are determined by the local climatic and soil conditions, it is reasonable to assume $B_1 = B_2 = B$. Hence, we have

$$\frac{dx_1}{dt} = A1x1 (1 - \frac{x_1}{B}) \qquad (3)$$

for rubber in an intercropped plantation; and

$$\frac{dx_2}{dt} = A2x2 (1 - \frac{x_2+x_1}{B}) \qquad (4)$$

for pepper in the same intercropped plantation.

After integrating equation (3) we find

$$x_1 = B(1 + (\frac{B-x_{01}}{x_{01}}) e^{-A_1t})^{-1} \qquad (5)$$

where x_{01} is the initial biomass of rubber.

It is difficult to integrate the equation (4). But we may assume that in the beginning, the growth of pepper is synchronous with the growth of rubber. Hence we may put $x_2 = x_1$ where is a proportional constant. Substituting $x_2 = x_1$ into equation (4), we find

$$\frac{dx_2}{dt} = A_2x_2 (1 - \frac{(1+\frac{1}{\alpha})x_2}{B}) \qquad (6)$$

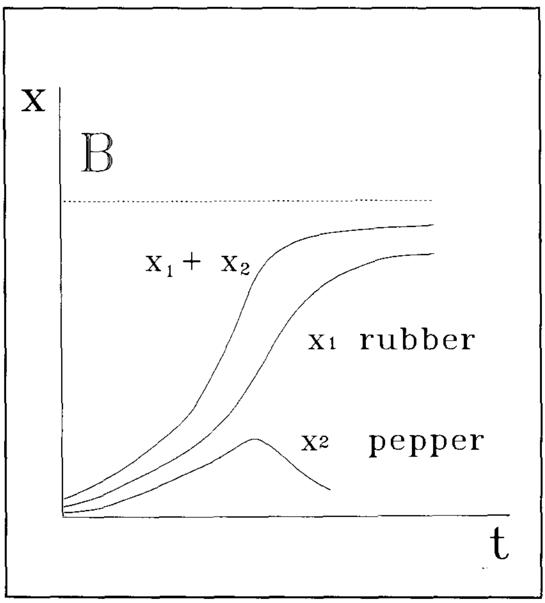

***Fig. 1** Growth curves of rubber and pepper in an intercropping system.*

Table 2. Fertility densities of rubber plantations in China at different periods

Year	Organic matter (%)		Quick-acting P (ppm)		Quick-acting K (ppm)	
	Intercropped	Monoculture	Intercropped	Monoculture	Intercropped	Monoculture
1979*	1.07	0.88	48.6	15.7	51.0	15.0
1978	1.78	1.71	60.0	47.0	53.0	30.0
1979	1.75	1.72	62.2	15.5	45.5	26.6
1980	1.93	1.91	63.5	6.48	37.5	21.3
1981	2.05	2.08	59.6	19.6	62.5	22.0

$$= A_2X_2\left(1 - \frac{\frac{x_2}{B}}{1+\frac{1}{\alpha}}\right)$$

Making integration to (6), we find

$$x_2 = D\frac{1}{1+\frac{D-x_{02}}{x_{02}}e^{A_{2t}}} \quad (7)$$

$$D = B\frac{1}{1+\frac{1}{\alpha}}$$

wherex$_{02}$ is the initial biomass of pepper. And the total biomass of rubber and pepper will be

$$x_1+x_2 = B(1+\frac{B-x_{01}}{x_{01}}e^{-A_{1t}}) + D(1+\frac{D-x_{02}}{x_{02}}e^{A_{2t}}) \quad \mathbf{(8)}$$

where

$$D = B\frac{1}{1+\frac{1}{\alpha}}$$

The growing curves of both rubber and pepper in an intercropped planation will be shown schematically in Fig. 1. Whether the intercropping system will be accepted and carried out or not is not mainly decided by how much the biomass produced, but by how the results of the ecological economic effects are.

The Effects of Intercropping

The vegetation coverage in an intercropped plantation of rubber with pepper is more than 80% in the third year of intercropping (the rubber spacing is 2 x 10 m), whereas the vegetation coverage of a monocultural rubber plantation is usually less than 50% (not including weeds). Hence, more vegetation coverage will reduce soil erosion effectively. According to some measurements, both the amount of run off after rainfall and the amount of soil eroded in an intercropped field will be reduced by more than 50% of a monocultural field. Furthermore, according to the measurement made at Xingnong Experimental Station in Hainan Island, the fallen withered matter in an intercropped rubber plantation amounted to 7,500-9,000 kg/ha/yr, whereas the fallen withered matter in monocultural rubber plantation was only 3,546 kg/ha/yr. Besides the additional application of fertilisers to pepper, both the organic content and some quick-acting P and K content in an intercropped soil were greater than in monocultural soil (see Table 2).

The annual yield of pepper seed amounted to 150-300 kg/yr in intercropped plantation valued 2,250-4,500 RMB/ha. After deducting the production cost the net profit for intercropping was about 1,000 RMB/ha/yr.

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Intercropping Pineapple Under Eucalyptus Plantation and the Economic Benefits

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ABSTRACT

The practices and economic benefits of intercropping pineapple in Eucalyptus plantations at the Baishiling State Forest Farm of Qionghai County, Hainan Province are summarised in the paper. The first harvest of pineapple is obtained two years after planting and the total yield of the first four years is 14,234.8 kg/ha. Excluding the investment for plantation establishment, tending and harvesting costs, the net economic profit is 3,045.78 CNY/ha. Simultaneously, intercropping brings about great advances in the growth of trees. The timber volume accumulation of intercropped stands is twice as much as that of the non-intercropped stands. This kind of intercropping system has great potential for development.

Key Words *Intercropping; pineapple; Eucalyptus; economic benefit*

Introduction

Intercropping is an important planting system in tropical China. But most of them report intercropping systems with rubber, coconut and other agricultural or economic plants. An experiment on intercropping pineapple in *Eucalyptus* plantations was started at the Baishiling Forest Farm of Qionghai County, Hainan Province in 1983. The results of the five-year experiment showed that it is a good planting system for the area and has great potential for development, the details are given in this paper.

Materials and Methods

Site Description -

The experimental trials were conducted in Paitian Work Area (Site 1, 30 ha) and behind hill of head office (Site 2, 10 ha) of the Baishiling State Forest Farm located at 111°28'E longitude and 19°13'N latitude with an annual mean temperature of 24°C and annual rainfall of 2,070 mm. The soil is poor laterite with high sand content. The site used to be covered by secondary shrubby vegetation.

Establishment and Management of Experimental Plantations -

The planting holes sized 40 x 40 x 35 cm were dug after site preparation (clearing the shrub at Site 1 and completely ploughing at Site 2). The spacing adapted for planting trees was 1 x 2.5 m. One hundred grams calcium superphosphate was applied to each tree planting hole as base fertiliser. The forest tree species used were *Eucalyptus exserta* at Site 1 and *Eucalyptus leizhou* No. 1 at Site 2. The plantations were established in March 1983 and April 1985 at Site 1 and Site 2 respectively.

Table 1. Growth comparison of intercropped and non-intercropped stands

Site	Species	Intercropped				Non-intercropped		
		Age (yr)	DBH (cm)	Height (m)	Volume (m^3/ha)	DBH (cm)	Height (m)	Volume (m^3/ha)
1	*E. exserta*	5	8.07	10.07	95.614	6.42	9.53	47.372
2	*E. leizhou* No. 1	3	7.85	9.59	87.070	5.89	7.61	41.148

Table 2. Yield comparison of wood products

Site	Age (yr)	Intercropped					Non-intercropped				
		Yield		Value			Yield		Value		
		A* (m^3/ha)	B** (t/ha)	A*	B**	Total (RMB Yuan/ha)	A* (M^3/ha)	B** (t/ha)	A*	B**	Total (RMB Yuan/ha)
1	5	57.31	44.20	9,170	2,210	11,380	28.42	23.95	4,547	1,198	5,745
2	3	52.41	39.79	8,387	1,989	10,376	24.69	20.46	3,950	1,023	4,973

Table. 3 Yield and the value of pineapple from site 1

Time	Age (yr)	Yield (kg/ha)	Value (Yuan/ha)
6/1985	2	1,656.4	695.66
6/1986	3	3,988.3	1,962.90
6/1987	4	6,281.0	2,265.10
6/1988	5	2,309.1	942.30
Total		14,234.8	5,865.96

Young pineapple plants were intercropped between the tree rows at spacings of 0.5 x 0.5 x 1.0 m, four or five months after the trees were planted. The intercropped lands were 10 ha and 3 ha in Site 1 and Site 2 respectively, and the other areas were used as control. Fertilisation and cultivation were conducted once and one to two times respectively, every year in both the intercropped and non-intercropped stands, but the management activities to non-intercropped stands were stopped at two years after planting. The details of investment, pineapple yield and output value were recorded. The growth of trees was measured and the output value of woody products were estimated in March 1988.

Results

Tree Growth Comparison -

The tree growth data of intercropped and non-intercropped stands is listed in Table 1. The significant growth (dbh and height) differences were statistically (at prob. level of 99%) significant between the two types of stands (Fig. 1). The timber volume accumulation of intercropped stands was twice as much as that of non-intercropped stands (Table 1).

Yield Comparison of Estimated Wood Products -

Table 2 lists the estimated yield of wood products and the value of intercropped and non-intercropped stands according to the local existing prices of small timber and firewood. The value of intercropped stands was about two times more than that of non-intercropped stands.

Yield of Pineapple -

Pineapple, a tropical fruit, has the following characteristics: fast-growing, early maturing and high-yielding within 18-20 months from planting to flowering. The first harvest was at 22 months after planting and once a year thereafter. It can be harvested for four to five years. The yield and value of pineapples harvested in Site 1 is shown in Table 3. The total average yield of the first four harvested years is up to 14,234.8 kg/ha valued at 5,865.95 CNY/ha.

Economic Analysis -

The investment details for Site 1 are given in

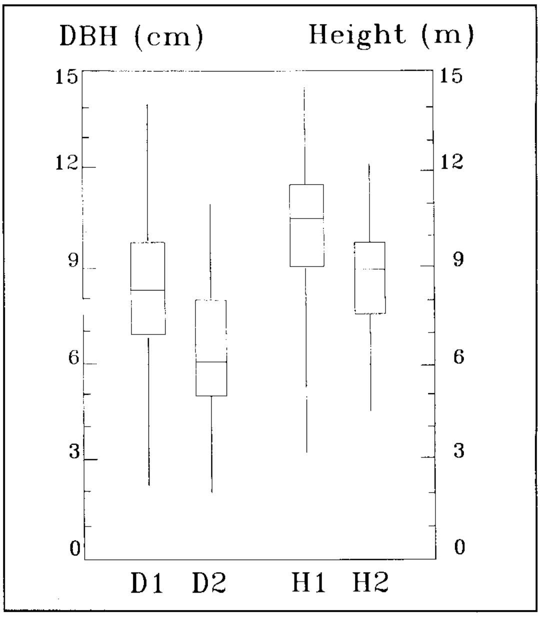

Fig. 1 *Box-&-Whisker plot to show the growth differences between intercropped and non-intercropped stands of Site 1 (D - Diameter at breast height, H - Tree height, 1 - Intercropped; 2 - Non-intercropped)*

Table 4. Investment details for the planting systems (Chinese Yuan (RMB)/ha)

Year	Intercropped						Non-intercropped		
	Planting		Tending		Harvest	Total	Planting	Tending	Total
	T*	P*	C**	F**					
1	750	700	69	206	-	1,931.00	750	110	860
2	-	-	60	96	23.19	179.19	-	145	145
3	-	-	40	120	55.75	215.75	-	-	-
4	-	-	60	127	87.93	274.93	-	-	-
5	-	-	60	127	32.33	219.33	-	-	-
Total	750	700	289	676	199.20	2,614.20	750	255	1,005

*T - Trees P - Pinaapple **C - Cultivation F-Fertiliser*

Table 5. Economic benefit comparison of the two planting systems (Chinese Yuan (RMB)/ha)

Year	Intercropped				Non-intercropped		
	Output Value		Cost	Accumulative Profit	Output Value	Cost	Accumulative Profit
	Trees	Pineapple					
1	-	-	1,931.00	-1,931.00	-	860.00	-860.00
2	-	695.70	179.17	-1,414.49	-	145.00	-1,005.00
3	-	1,962.90	215.75	+332.66	-	-	-1,005.00
4	-	2,265.10	274.95	+2,322.81	-	-	-1,005.00
5	-	942.30	219.33	+3,045.78	-	-	-1,005.00
	11,379.80*			+14,425.58*	4,973.70*		+3,968.70

Estimated

Table 4. Intercropped stands need tending, fertilising and harvesting every year, including the costs of plantation. The investment for the first five years was 2,614.2 CNY/ha. The management activities for the non-intercropped stand were carried out in the first two years, with the cost for plantation establishment which was 1,005.00 CNY/ha. Although a big investment is needed for managing intercropping systems, income can be obtained early (two years after planting), and the investment can be completely recovered in the first two to three years. But the farmers need to wait for eight to ten years to get the money back from the wood products if they manage only monocultural stands of trees. In Table 5, we can see the differences in economic benefits between the two planting systems.

Conclusion

The experimental results showed that the intercrop of pineapple in *Eucalyptus* plantation is a promising system in tropical China. It has many advantages such as increasing the productivity of land, shortening the cycle of money rotation, and promoting forestry development. It has great potential for development in southern China, especially in the areas with high population density where there is limited usable land.

Acknowledgement

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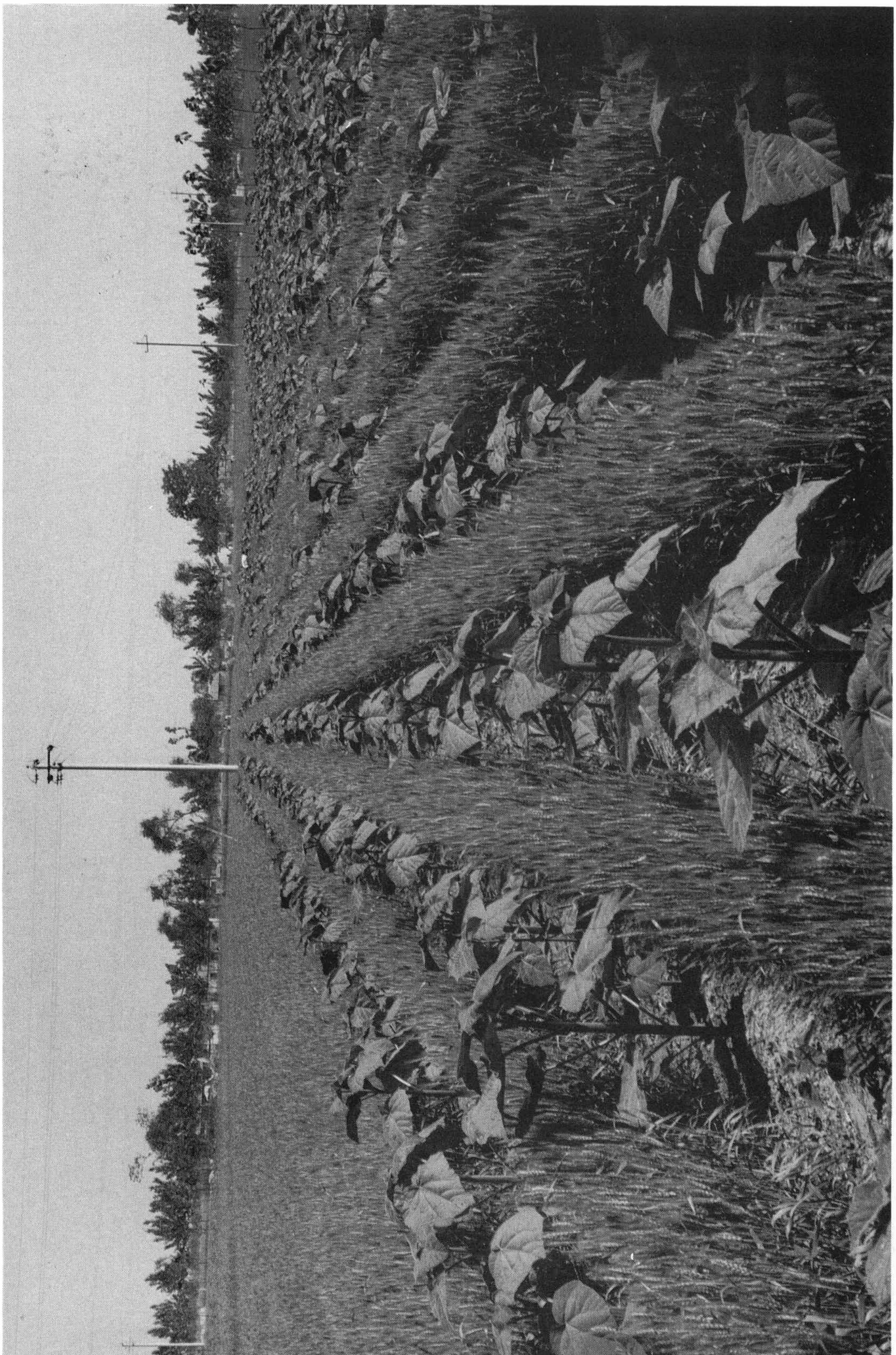
Acacia (Acacia confusa) - Tea (Camellia sinensis) Interplanting

Agroforestry System (Forestry-Fishery-Agronomy) with water canal (Lixiahe, Jiangsu)



Wheat Intercropped in Paulownia Nursery (Yanzhou, Shandong)

Poplar (*Populus euramericana I-214*) - Wheat Intercropping (Yanzhou, Shandong)

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