Genetic diversity for sustainable rice blast management in China: Adoption and impact

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Genetic diversity for sustainable rice blast management in China: Adoption and impact

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Abstract

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The experience on rice blast in Yunnan Province, China, is one of the most successful and widely publicized examples of genetic diversification for disease suppression in practice. The wet, cool climate of the province is highly favourable for the development of rice blast epidemics. Before 1998, farmers had to spray fungicides three to eight times per cropping season to successfully grow a crop of glutinous or sticky rice. To reduce farmers' dependence on these harmful agrochemicals, a team of scientists from the International Rice Research Institute (IRRI) and Yunnan Agricultural University (YAU) initiated a project in Yunnan Province with the objective to explore the possibilities of using biodiversity as a means to control blast outbreaks, and through the associated increase in productivity and income, contribute to poverty alleviation.

This study focuses on the effects of the developed technology, i.e., interplanting one row of high-value, but blast-susceptible glutinous rice, with four to six rows of blast-resistant hybrid *indica* rice varieties, on blast management and the socio-economics, i.e., productivity and farm income, as a basis for explaining its adoption.

In a field experiment in Gejiu, Yunnan Province, it was shown that niche differentiation, leading to resource complementarity between the two rice varieties, was marginal and hardly increased the land productivity of the rice varietal mixtures. Prevention of lodging of glutinous rice appeared an important additional advantage of growing rice in varietal mixtures. Results of farm surveys involving both, adopters and non-adopters, showed that contact with extension workers and farmers' perceptions of the technology-specific attributes of the rice varietal mixtures were the major factors determining adoption probability and use intensity. Adoption of rice interplanting resulted in increased technical efficiency. Longer farming experience and access to extension agents were both significantly positively correlated with technical efficiency.

The rice interplanting system in Yunnan has clearly shown that it is possible to combine modern and traditional rice varieties to control blast disease, attain acceptable crop production and provide high-quality food and income for the rural population. The Yunnan experience has also demonstrated that the best way to transfer a technology from concept to actual practice is to strengthen the links among research, extension, policy makers and farmer communities.

Keywords: Disease management, genetic diversity, rice interplanting, competition, resource complementarity, technical efficiency, production function, *Magnaporthe grisea*

Preface

My research involvement in the project “Exploiting biodiversity for sustainable pest management in China” began when I joined the field trip-cum-workshop in Yunnan in July 1999. The enthusiasm of the farmer participants and the scientists working in the project was so contagious that it inspired me to conduct an on-the-spot interview of a few farmers just to get a quick and simple estimate of the costs and benefits of using the rice varietal mixtures in Yunnan. Little did I know then that this project would pave the way for my PhD programme. In December 2000, I was awarded an IRRI-Wageningen Shuttle Sandwich PhD Fellowship at Wageningen University. Although I was admitted to the programme with a different project proposal, I eventually took up the challenge of assessing the impact of rice varietal mixtures on farmers’ pest management, farm productivity and income.

This study could not have been completed without the generous support of many individuals. First of all, I would like to express my gratitude to Prof. dr. ir. Herman van Keulen, my promotor, and Dr. ir. Lammert Bastiaans, my co-promotor, who saw the study through various stages until its completion, for their excellent thesis supervision.

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Mel Revilla-Molina,
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List of Abbreviations

ADB	Asian Development Bank
CIAT	Centro Internacional de Agricultura Tropical
DAS	days after sowing
DMCs	developing member countries
DNA	desoxyribonucleic acid
Foc	*Fusarium oxysporum* f. sp. *Cubense*
GR	glutinous rice
HR	hybrid rice
IABGRRI	Indonesian Agricultural Biotechnology and Genetic Resources Research Institute
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
LGU	local government units
LR	likelihood ratio
LSM	least squares means
MVs	modern varieties
NARS	national agricultural research systems
NDI	niche differentiation index
NH_4HCO_3	ammonium bicarbonate
NILs	near-isogenic lines
$Ca(H_2PO_4)_2$	superphosphate
PDA	Provincial Department of Agriculture
PhilRice	Philippine Rice Research Institute
PRC	People’s Republic of China
RY	relative yield
RYT	relative yield total
SEM	standard error of means
USA	United States of America
YAU	Yunnan Agricultural University

CHAPTER 1

General introduction

In the mid-1960s, the Green Revolution resulted in a dramatic increase in food production as a result of a combination of advances in the field of plant breeding and production-oriented intensification of agriculture, stimulated by the implementation of enabling policies. This technological revolution integrated the development and use of modern high-yielding varieties and led to an increase in both, level and efficiency of agricultural production (Evenson and Gollin, 2003). However, one of the consequences of this development was an equally dramatic decline in the diversity of plant species and varieties on which the global population depends (Smale, 1997).

There are two relevant aspects in the reduction in species diversity in modern agro-ecoystems. The first is the general decline in the number of species used by man for the production of food, feed and fibre. Over the years, the trend has been to use increasingly fewer plant species/varieties and driven by both, the economies of scale and the prevalent emphasis in plant breeding, to concentrate on those that give the highest return per unit land and/or labour. Today, as a result, the human population is fed to a large extent by only 15 plant species (Marshall, 1977). The Green Revolution and modern agriculture are, thus, characterized by genetic homogeneity.

A second related aspect is the decline in spatial and temporal species/varietal diversity within farms and regions. In traditional agricultural systems, farming communities were characterized by farmers growing a variety of crops. Because of increasing globalization, following the principle of comparative advantage, farmers and regions increasingly specialized in a limited number of crop species. Consequently, modern agricultural systems are characterized by a small number of crop species grown in monocultures.

Specific simplicity and genetic uniformity of modern agricultural plant communities offered advantages to farmers, as well as to consumers and processors. The genotypic and phenotypic uniformity of modern cultivars permit farmers to fully exploit the increase in efficiency in terms of yield per unit area *vis-à-vis* mechanization, fertilization, irrigation, harvesting and storage, and other land- and labour productivity-enhancing activities.

Hazards of genetic homogeneity

Genetic uniformity as present in monocultures has been widely recognized as a crucial factor in stimulating the development of pests and diseases and the subsequent development of epidemics. The literature is replete with examples:

1. Potato late blight is caused by the fungus *Phytophthora infestans*. Best known for causing the devastating crop losses that resulted in the Irish potato famine in 1845, this fungus infects leaves, stems and tubers (e.g., Woodham-Smith, 1962).
2. Southern corn leaf blight incited by *Helminthosporium maydis* Nisikado & Miyake in the corn belt of the USA is of great significance in the history of American agriculture, because of its epidemic proportions in 1970 and the subsequent devastation of much of the corn crop that year. The monetary loss as a result of the epidemic has been estimated at US$1 billion (Ullstrup, 1972).
3. Sugarcane rust caused by *Puccinia melanocephela* resulted in an epidemic in Cuba in 1979–1980 that led to the destruction of 30% of the Barbados 4342 variety of sugar cane, costing Cuba some 1,355,000 tons of sugar (Alvarez, 2005).
4. *Fusarium* wilt (Panama disease) is a destructive fungal disease of banana plants. It is caused by *Fusarium oxysporum* f. sp. *cubense* (*Foc*). It first became epidemic in Panama in 1890 and proceeded to devastate in the 1950s and 1960s the Central American and Caribbean banana industries that were based on the ‘Gros Michel’ (AAA) variety. Once *Foc* is present in the soil, it cannot be eliminated (e.g., Molina, 2004).
5. Brown spot disease caused by *Cochliobolus miyabeanus* (formerly *Helminthosporium oryzae*) affecting the rice crop led to the great Bengal famine in 1942 (e.g., Padmanabhan, 1973).
6. The brown planthopper (Brar and Khush, 1997) and tungro virus (Savary et al., 1993) epidemics in rice in the Philippines in the 1970s were associated with the large areas planted to modern high-yielding rice varieties such as the IR varieties.

Rice blast disease is another example. Rice blast, caused by the fungus *Magnaporthe grisea* is one of the most destructive diseases of rice, because of its wide distribution and destructiveness under favourable conditions (Ou, 1985). It can cause severe yield losses where environmental conditions are favourable for disease development (Greer and Webster, 2001). In general, long periods of leaf wetness, high relative humidity, and temperatures of 17–28 °C favour rice blast development (Webster and Gunnel, 1992).

Bastiaans (1993) reported that rice is most susceptible to blast in the seedbed, and at the tillering stage of the crop. The fungus that causes blast disease spreads through multiple asexual spore production cycles throughout the cropping season, while causing necrotic spots on leaves and necrosis (death) of the rice panicles.

During the early growth stages, lesions are mainly formed on the leaves, resulting in a more than proportional reduction in leaf photosynthetic rate (Bastiaans, 1991). Lesion formation on leaves is followed by premature leaf senescence of infected tissue, especially in case of heavy infections. The highest fraction of leaf area covered by lesions is usually reached around maximum tillering, followed by a gradual decline in disease severity due to adult plant resistance. With time, resistance of newly formed leaf tissue increases and leaves that appear on physiologically older plants obtain this property faster (Roumen, 1993). Thus, leaf blast is mainly observed before flowering.

After heading, blast may infect the panicle or the neck node. Panicle blast causes direct yield losses, since filling of the grains in infected panicles is poor at best. As it occurs late in the season, when a farmer has already made all investments in production inputs, panicle blast is considered the most serious phase of blast disease.

Yunnan Province

Yunnan Province is the eighth largest province of the People's Republic of China (PRC) with a total land area of 396,790 km^2. Historically, it is one of the poorest, less developed provinces in the country, with an annual per capita income of 4,851 RMB (1 US$ = 8.2 RMB) in 2005. Located in south-west China, from 20° to 29° N latitude and from 97° to 196° E longitude, the highest elevation is 2,700 m in Lin Lang County and the lowest 76 m in Hekon County (Figure 1). The Yunnan Plateau has many plains, which are the main agricultural areas, especially for rice production.

Rice production in Yunnan is intensive and its yield potential is high. Rice is usually grown before a crop of wheat, lima bean, potato, maize, and sometimes tobacco. *Japonica* rice is grown in high-elevated areas (> 1600 m), whereas *indica* rice is grown at lower elevations. Prior to 1998, more than 98% of the *indica* rice areas were grown to the hybrid varieties Shanyou 22 and Shanyou 63, with yields averaging more than 8 t ha^{-1}. The remainder of the area was planted to specialty rice – mostly traditional varieties – that are difficult to grow, because of proneness to lodging, and susceptibility to various diseases. The most destructive of these diseases is rice blast that caused the yield in general to be very low.

The wet, cool climate of the province is highly favourable for the development of rice blast epidemics. Throughout its history of rice cultivation, therefore, blast outbreaks have caused serious yield losses. Following the incorporation of resistance genes, rice blast is no longer a serious problem in the hybrid *indica* rice varieties and normally does not cause significant yield losses (Shen and Lin, 1994, 1996). When a new race or pathotype evolved that overcame the resistance, the variety was replaced by a new variety with a new resistance gene. However, the blast disease remained a serious problem in glutinous and other traditional high-quality rice varieties, because

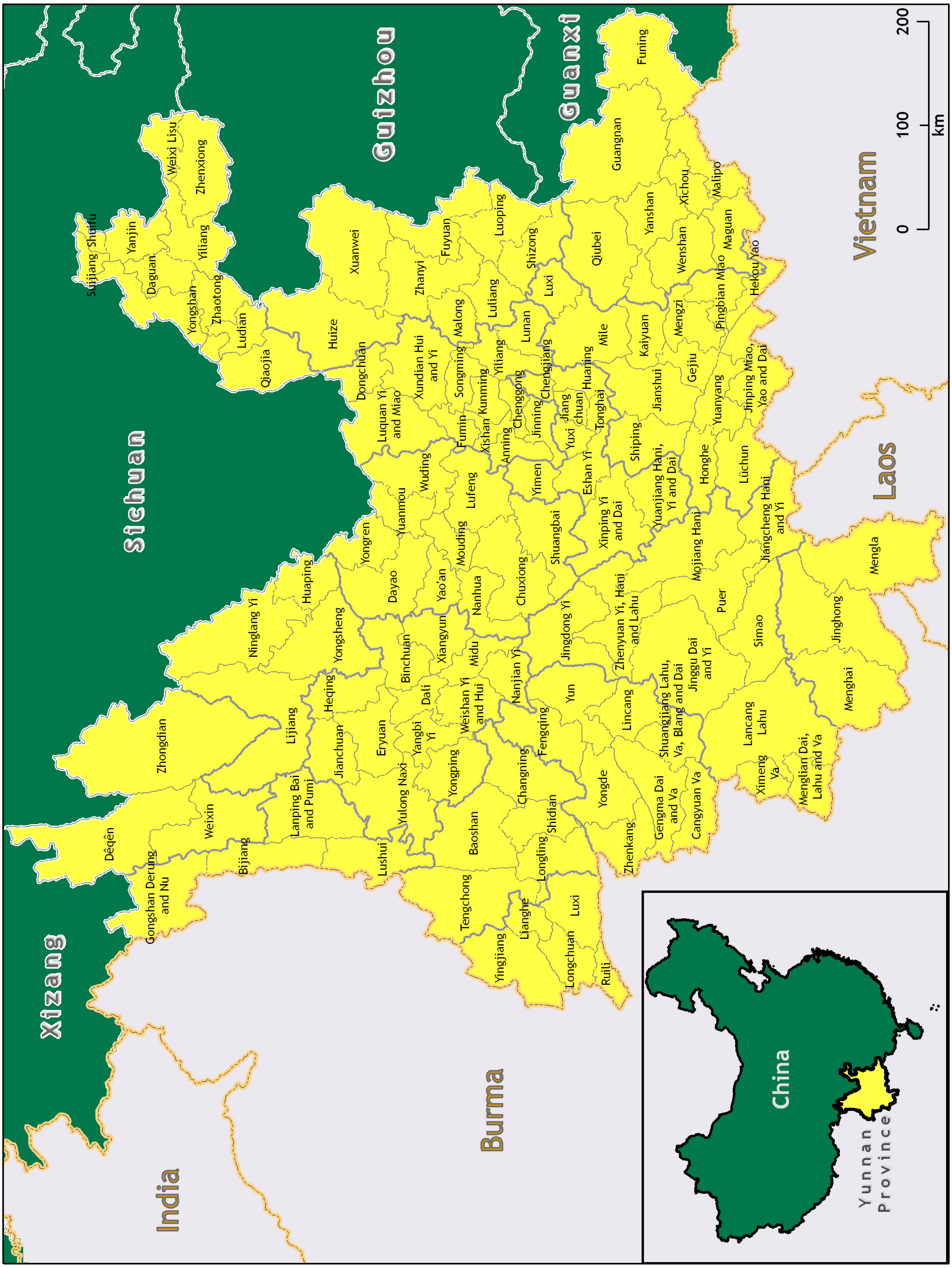

Figure 1. Map of Yunnan Province with Counties, in the Peoples Republic of China.

of relatively little effort to improve these varieties through resistance breeding. Glutinous or sticky rice varieties have much higher socio-cultural and market values than hybrid rice, because they are used for confections and other specialty dishes. However, farmers growing glutinous varieties had to apply three to eight foliar sprays of fungicide per season to obtain a reasonable marketable yield.

The shift to the rice interplanting system

Concerns about the health and environmental effects of pesticides have increased over the past decades (Rola and Pingali, 1993). These concerns are evident among others from the increase in scholarly work on the environmental impacts of pesticides in the United States and in Europe (e.g., Liem et al., 2000; Schafer and Kegley, 2002; Porta, et al., 2008). In addition to human health effects, (over)use or injudicious use of pesticides can also result in serious negative effects on the environmental quality of surface water, groundwater, and air, which consequently may harm birds, aquatic species, mammals, as well as beneficial insects (such as natural pest enemies). Misuse of pesticides may thus negatively affect the predator-prey balance and result in higher levels of pest infestation and disrupt the existing ecosystem balance (Higley and Wintersteen, 1992; Mullen et al., 1997).

In response to the societal concerns on the negative effects of biocides, Integrated Pest Management (IPM) systems have been developed (Zadoks and Schein, 1979). Such systems utilize, in the context of the specific environment and the population dynamics of the pest species, all suitable techniques and methods in as compatible a manner as possible, to maintain the pest populations at levels below those causing economically unacceptable damage or loss. Such systems represent an attractive option, as they guarantee yields, reduce costs, are environmentally-friendly and contribute to the sustainability of agriculture (Kenmore, 1991).

An alternative approach has been the purposeful introduction of biodiversity in cropping systems as a means of preventing pest outbreaks, prevailing in monoculture crops. Jensen (1952) was one of the first authors to formally promote the use of genetic diversity in agriculture through the development of multiline oat (*Avena sativa*) cultivars via mixtures of genotypes that are selected for phenotypic uniformity, but genetically as diverse as possible for other traits, such as disease resistance. Later, Borlaugh (1959) and Frey et al. (1973) utilized a backcrossing approach to produce multilines of wheat and oats, respectively that contained different genes for race-specific resistance to rust (*Puccinia* spp.) pathogens.

Multiline cultivars have had significant commercial success (Browning and Frey, 1981; Mundt and Browning, 1985), but recently more attention has been focused on the use of cultivar mixtures (Akem et al., 2000) without further selection for uniformity among mixture components (Mundt, 1994). Cultivar mixtures have shown success and acceptance as a means of disease control, especially for cereals. One typical example is the experience of rice farmers in Yunnan Province, China.

In 1997, a team of scientists from the International Rice Research Institute (IRRI) and Yunnan Agricultural University (YAU) initiated an Asian Development Bank (ADB)-funded project to explore the use of biodiversity through rice interplanting for blast disease management in Yunnan Province. The main objective of the project was environmental protection by reducing farmers' dependence on harmful agrochemicals, but since the project area is among the extremely poor areas in China, an increase in farm productivity and income from the adoption of rice interplanting would make a direct contribution to poverty alleviation.

With guidance from scientists and extension workers, farmers in Yunnan interplanted one row of high-value, but blast-susceptible glutinous rice, with four to six rows of resistant hybrid *indica* rice varieties, instead of the customary technology of planting rice in monocultures. With this single change, farmers were not only able to control rice blast, but also boosted the yields of glutinous rice and thereby increased their income.

The scientific hypothesis underlying the use of genetic biodiversity for disease suppression was simple. If a variety of a crop is susceptible to a disease, the more concentrated the plants of that variety are, the more easily the disease can spread and the more plants it can infect. The disease is less likely to spread if susceptible plants are separated from each other by other plants that are resistant and can act as a barrier and increase the distance between susceptible plants (dilution effect) (Wolfe, 1985).

While Zhu et al. (2000) have demonstrated that genetic heterogeneity provides disease suppression and also increases the productivity of the land, knowledge gaps still exist. Is the yield increase in rice interplanting completely caused by the absence of blast or do other mechanisms play a role? A component cultivar may benefit another component directly through reduced competitive pressure, following from niche differentiation, by providing physical support or windbreaks that might prevent lodging, or by improving the microclimate, that might result in protection against pests and diseases (Callaway, 1995; Garcia-Barrios, 2002; Castilla et al., 2003).

Technology adoption and diffusion

Technology adoption, in general, is often a difficult and long-term process, even when a newly developed technology has obvious advantages (Rogers, 1995). In many cases, introduction of new technologies has met with only partial success, as expressed in observed rates of adoption. According to Rogers (1995), the variance in the rate of technology adoption can be explained by the five perceived attributes of a new technology: relative advantage, compatibility, complexity, trialability and observability. As past experience shows, immediate and uniform adoption is quite rare (Gollin et al., 2005). Some innovations have been well received, while others have been adopted by only a very small group of farmers.

The rice varietal mixtures technology in Yunnan Province is one typical example of immediate and large-scale adoption of a new technology (Revilla et al., 2001, 2003; Leung et al., 2003; Chapters 3 and 6). In order to learn from the experience, we have to understand the process by which the technology of rice interplanting was introduced and scaled up to more farmers. What was the impact of adopting rice interplanting on farmers' pest management, yield and income? What were the key elements in the process of technology diffusion? What were the major factors that conditioned farmers' decision to adopt the rice varietal mixtures?

Technical efficiency

Efficiency is an important factor of productivity in developing countries where there are dwindling resources for adoption of improved technologies for increased production. A large number of papers has been published that have examined the efficiency of rice farmers in developing economies (e.g., Thiam et al., 2001), and a significant number focusing on China (e.g., Travers and Ma, 1994; Fan et al., 1994; Wang et al., 1996a, b; Xu and Jeffrey, 1998; Fan, 1999; Tian and Wan, 2000). In this context, stochastic frontier production functions have been used extensively in the past two decades to analyse technical efficiency, as well as statistically explain any observed inefficiency.

Following the adoption of rice varietal mixtures, we might be concerned with the issue of technical efficiency in rice production. Are rice farmers operating on their production frontiers after adopting rice interplanting? Will there be a change in the responsiveness of their outputs to inputs, e.g., labour, pesticides, fertilizer, etc.? What are the sources of inefficiency, if any?

Beyond the rice interplanting in Yunnan

The success of using increased biodiversity for disease suppression achieved in Yunnan Province has generated considerable interest in varietal diversification and at the same time raised a number of questions. Will it work for other rice diseases or in different rice production environments in other countries? Can a similar approach of diversifying the genetic landscape of a crop be extended to other crops?

Objectives and approach

The tendency in the literature is to concentrate on the effects of diversity on diseases or pests or weeds, or on particular species within these three main groups (Zadoks and Schein, 1979; Finckh and Wolfe, 2006). In this study, we attempt to analyse the effects of genetic diversity on blast management and to determine the socioeconomics of using genetic diversity, rice interplanting in this case, in explaining the adoption and impact on farmers' pest management, productivity and income.

We used a three-pronged approach to address five different objectives. The first objective was to elucidate the importance of complementarity (niche differentiation) and prevention of lodging in the fast-spreading practice of growing rice varietal mixtures. For this purpose, we conducted a field experiment in Gejiu, Yunnan Province during the wet season of 2002.

We also conducted two farm surveys, one in July and one in October 2000, each consisting of a random sample of *ca* 100 farmer-adopters and 30 nonadopters of rice interplanting in Yunnan Province. These data were collected to address the following socioeconomics-related objectives: (i) to analyse the impact of mixture planting on pest management and farmers' income: (ii) to determine how farmers' perception of technology characteristics affected their decision to adopt rice varietal mixtures; and (iii) to analyse the effect of interplanting on technical efficiency of rice production.

Lastly, we reviewed the status of rice disease management and the knowledge and tools available for deployment strategies. We then highlight the experiments conducted in Yunnan and present additional case studies to explore options for extending the diversification concept to other diseases and cropping systems.

Outline of the thesis

This thesis consists of a general introduction (Chapter 1), five research papers (Chapters 2–6) and a general discussion (Chapter 7). Chapter 2 examines the competitive relations within the rice mixtures system in China. Chapter 3 presents a historical perspective of the diffusion and adoption of the rice interplanting technology in Yunnan Province and assesses its impact on pest management and farmers' income. Chapter 4 examines which farmers were most prone to adoption, and how farmers' perception of technology characteristics affected their decision to adopt rice varietal mixtures. Chapter 5 analyses the technical efficiency of rice production in Yunnan Province and identifies the sources of inefficiency. Chapter 6 discusses a research 'road map' leading to the use of functional diversity to control rice blast and how the experience gained in Yunnan can be extended to other diseases, crops and agro-ecosystems in developing countries. A general discussion of all the results and conclusions is presented in Chapter 7.

CHAPTER 2

Does resource complementarity or prevention of lodging contribute to the increased productivity of rice varietal mixtures in Yunnan, China?

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Abstract
We conducted an experiment in Gejiu, Yunnan Province of China during the wet season of 2002 to examine the importance of resource complementarity and prevention of lodging in the fast-spreading practice of growing rice varietal mixtures in China to suppress rice blast damage. The hybrid rice variety Shanyou 63 and the glutinous or sticky rice variety Huangkenuo were used to study intra- and inter-varietal competition in the rice intercropping system. The experiment was laid out as a randomized complete block design in four replications with pure stands and mixtures of both varieties at different total planting densities and mixing ratios. In half of the pure stand treatments of glutinous rice a metal frame was installed to prevent lodging. The results showed that resource complementarity between the two rice varieties resulting from niche differentiation was marginal and did not greatly enhance the productivity of the rice varietal mixtures. In contrast, prevention of lodging of glutinous rice was identified as an important additional advantage of growing rice in varietal mixtures.

Keywords: Rice mixtures, lodging, facilitation, relative yield total, competition, niche differentiation

Introduction

Rice blast epidemics, caused by the fungal pathogen *Magnaporthe grisea*, can result in significant yield losses. The disease has been a major production constraint of the popular and important glutinous rice cultivars in Southern China. These glutinous rice cultivars have higher market and cultural value than other rice types, as they are used for confections and other specialty dishes. The wet, cool climate of Yunnan Province in particular, is highly favourable for development of rice blast epidemics. Farmers normally apply 3–8 foliar fungicide sprays to control the disease in susceptible varieties. The availability of higher yielding and blast-resistant rice hybrids has eventually led to nearly complete displacement of the lower yielding and highly susceptible glutinous rice.

Increasing plant biodiversity in cropping systems has been considered a strategy to enhance the resilience of the ecosystem to withstand epidemics (Browning and Frey, 1969; Wolfe, 1985, 2000). Research by Yunnan Agricultural University in China, in collaboration with IRRI, has provided evidence that crop diversity is a possible strategy to manage blast disease in cropping systems that contain the blast-susceptible glutinous rice cultivars. Zhu et al. (2000) have shown that genetic diversification of the rice crop provides an ecological approach to disease management that can be highly effective in large-scale rice production systems.

In this system, single rows of traditional, blast-susceptible glutinous varieties are interplanted between groups of four to six rows of modern, resistant hybrid rice. The results of the 1998–99 experiments conducted in Yunnan have been spectacular. Blast disease severity in traditional rice varieties decreased by 94% and the increase in grain yield of the glutinous rice variety was 89% (Zhu et al., 2000). Grain yields of the hybrids in mixture were nearly equal to the yields obtained in monocultures. The simplicity and effectiveness of this approach have attracted active participation and adoption by farmers in China (Revilla et al., 2001, 2003; Chapter 3).

While Zhu et al. (2000) have demonstrated that genetic heterogeneity provides disease suppression and increases the productivity per unit land area,, knowledge gaps still remain. Can the yield increase in the mixed system completely be explained by the disease suppression or do other mechanisms play a role, such as complementarity in capture and utilization of resources or prevention of lodging? This research aims at elucidating the importance of resource complementarity and prevention of lodging in the fast-spreading practice of growing rice varietal mixtures in China.

Material and methods

Experimental set up

The study was conducted during the wet season of 2002 in Gejiu, Yunnan Province of China (23.371 °N, 103.127 °E), located in a rugged region near the border with Vietnam. Rice in this area is commonly grown annually from March to August. Average temperature during this period is 23 °C and rainfall on average measures 134 mm.

The hybrid rice variety Shanyou 63 (HR) and the glutinous or sticky rice variety Huangkenuo (GR) were used to study intra- and inter-varietal competition in the rice intercropping system. Seeds of both varieties were sown on a wet-bed for seedling production on March 13. Seedlings were transplanted into the experimental field at 45 days after sowing (DAS) in hills of 4–5 plants for the low tillering glutinous rice variety and 1 plant per hill for the hybrid rice. The experiment was laid out as a randomized complete block design in four replications. Individual plots (3.60 m × 5.70 m) consisted of 24 rows with an inter-row distance of 0.15 m and a row length of 5.70 m. The in-row distance between hills was 0.15 m for the hybrid rice and 0.30 m for the glutinous rice. The experiment comprised 14 treatments, consisting of pure stands and mixtures of both rice varieties in different planting densities and density combinations (Table 1). Different planting densities were created by leaving out complete rows. Two sets of three pure stands of transplanted glutinous rice were established. In one of those sets height-adjustable metal frames were installed to provide plant support to prevent lodging.

Superphosphate ($Ca(H_2PO_4)_2$) and ammonium bicarbonate (NH_4HCO_3) were applied as basal dressing, at a rate of 100 and 75 kg ha^{-1}, respectively. Urea fertilizer was topdressed at a rate of 50 kg ha^{-1} at panicle initiation, i.e., 48 days after transplanting. Plots were sprayed with 135 kg Bufropezin insecticide mixed with 225 kg of water against *Sogatella furcifera* on June 10. A mixture of 225 ml of Cypermethrin in 225 kg of water, against *Scirpophaga incertulas* and *Chilo suppresalis* was sprayed on June 17 and 29. Hand weeding was performed on June 13.

Data collection and analysis

At maturity (162–167 DAS), grain yield estimates were based on a 2.70 × 1.80 m^2 area in the middle of each experimental plot. All hills in the yield estimate area were hand-harvested and then threshed. Yield samples were sundried and moisture content of each sample was determined using a moisture tester (Riceter L, Kett Electric Laboratory, Japan). In mixtures, individual varieties were evaluated separately, after which their yields were added to obtain the combined yield per hectare. Grain yields were expressed at 14% moisture content.

Table 1. Description of treatments, with number of rows occupied and corresponding hill density by variety, for the rice mixed planting experiment. The intra-row distance between hills was 0.15 m for the hybrid rice (HR) and 0.30 m for the glutinous rice (GR).

Treatment description (T)	Density combination[a]		Hill density (no. of hills m^{-2})	
	HR	GR	HR	GR
Pure stand hybrid rice				
1 Farmers' practice	8		29.6	
2 High density	12		44.4	
3 Medium density	10		37.0	
4 Low density	6		22.2	
Mixtures hybrid and glutinous rice				
5 Farmers' practice	8	2	29.6	3.7
6 High density	8	4	29.6	7.4
7 Medium density	4	4	14.8	7.4
8 Low density	3	3	11.1	5.6
Pure stand glutinous rice; without frame				
9 Farmers' practice		8		14.8
10 High density		12		22.2
11 Low density		6		11.1
Pure stand glutinous rice; with frame				
12 Farmers' practice		8		14.8
13 High density		12		22.2
14 Low density		6		11.1

[a] Number of rows out of 12 occupied by each variety.

For the yield components, five panicles in each plot were randomly sampled to determine the number of grains per panicle. A sample of 200 kernels was weighed to determine 1000-grain weight. Analysis of variance and comparison of means for yield and yield components were performed using the SAS statistical package. The means were compared by the least squares means (LSM) using Tukey's studentized range tests at 5% probability.

The experimental design contained two row-replacement series; one using farmers' density as reference (Table 2: T1, T9 and T12) complemented with a 50%–50% mixture (T7) and one using high densities as reference (T2, T10 and T13) complemented with a 67%–33% mixture (T6). Results of these replacement series, expressed in relative yield total (RYT), introduced by De Wit (1960) as an index of

Table 2. Summary of yield and yield components for different density combinations of hybrid (HR) and glutinous (GR) rice in the mixed planting experiment in Gejiu, Yunnan Province, China.

Trt	Density combination[a]		Grain yield ($Mg\ ha^{-1}$)			Grain yield $hill^{-1}$ (g)		No. of panicles $hill^{-1}$		Grains $panicle^{-1}$		1000-grain weight (g)	
No.	HR	GR	HR	GR	Total	HR	GR	HR	GR	HR	GR	HR	GR
1	8	0	7.12 ab	-	7.12 a	24.0 c	-	9.67 bc	-	85.6	-	29.1	-
2	12	0	7.58 a	-	7. 58 a	17.1 e	-	6.70 d	-	87.0	-	29.3	-
3	10	0	6.61 bc	-	6.61 abc	17.9 e	-	6.86 d	-	90.5	-	29.4	-
4	6	0	6.52 bc	-	6.52 abc	29.4 b	-	11.41 ab	-	86.7	-	30.1	-
5	8	2	6.15 c	0.71 e	6.86 ab	20.8 d	19.1 b	7.84 cd	10.69 a	91.6	76.7	29.3	27.8
6	8	4	5.05 d	1.36 de	6.41 abc	17.0 e	18.3 b	6.67 d	5.96 bc	88.3	100.7	30.0	30.8
7	4	4	3.69 e	1.72 bcd	5.40 bc	24.9 c	23.2 ab	10.07 b	7.94 ab	84.0	94.7	30.5	31.9
8	3	3	3.56 e	1.58 d	5.14 c	32.1 a	28.4 a	12.10 a	8.82 ab	92.8	101.1	29.0	31.8
9	0	8	-	2.81 ab	2.81 de	-	18.9 b	-	7.47 abc	-	79.1	-	31.3
10	0	12	-	1.69 cd	1.69 e	-	7.6 c	-	4.15 c	-	68.4	-	28.3
11	0	6	-	1.75 cd	1.75 e	-	15.8 b	-	6.94 bc	-	80.1	-	30.4
12	0	8	-	3.13 ab	3.13 de	-	21.1 ab	-	6.31 bc	-	82.6	-	31.3
13	0	12	-	3.51 a	3.51 d	-	15.8 b	-	5.34 bc	-	91.9	-	32.6
14	0	6	-	2.41 bc	2.41 de	-	21.7 ab	-	7.60 abc	-	89.3	-	32.4
S.E.M.			*0.253*	*0.303*	*0.326*	*0.97*	*2.97*	*0.70*	*1.43*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

[a] Number of rows out of 12 occupied by hybrid and/or glutinous rice varieties.

Column means followed by the same letter are not significantly different at ($P < 0.05$) Tukey.

biological performance, are presented in replacement diagrams. This index represents the sum of the relative yields of the two varieties in the mixture. Relative yield expresses the yield of the varieties in the mixture as proportion of its yield in pure stand. Replacement diagrams using pure stands of glutinous rice with and without plant support were drawn to examine whether prevention of lodging played a significant role in the superior performance of the mixed rice planting system.

Additionally, data on grain yield were analysed using the regression model approach for the quantification of intra- and inter-varietal competition using the procedure outlined by Spitters (1983). The advantage of this approach is that it does not have the prerequisite of replacement series and consequently all treatments can be included in the analysis. As the analysis aimed at elucidating whether niche differentiation between the two rice varieties occurred, only the pure stands of glutinous rice with a metal frame, and thus without lodging, were included in this analysis. Yield of variety 1 in mixture with variety 2 ($Y_{1,2}$; g m^{-2}) was written as:

$$Y_{1,2} = \frac{N_1}{b_{1,0} + b_{1,1}N_1 + b_{1,2}N_2} \tag{1}$$

where, N_1 and N_2 are hill densities (hills m^{-2}) of variety 1 (hybrid rice) and variety 2 (glutinous rice), respectively, $b_{1,0}$ is a parameter reflecting the reciprocal of the virtual grain yield of an isolated hill of variety 1 (hill g^{-1}), and $b_{1,1}$ and $b_{1,2}$ express the intra- and inter-varietal competition as experienced by variety 1 (m^2 g^{-1}), respectively. The ratio between these two parameters ($b_{1,1}/b_{1,2}$) denotes the relative competitive ability of variety 1 compared to variety 2, evaluated on a per hill basis and from the perspective of the first variety. A similar equation describes the grain yield of variety 2 in relation to the hill densities of both varieties, using the competition coefficients $b_{2,2}$ and $b_{2,1}$. In order to obtain estimates for the competition coefficients of both varieties, the yield density equation of Spitters (1983) was fitted to yields of the pure stands and the mixtures of each replicate separately, using the nonlinear regression procedure of SAS.

Based on all four competition coefficients combined, the niche differentiation index (*NDI*) was calculated (Spitters, 1983):

$$NDI = \frac{b_{1,1}}{b_{1,2}} \times \frac{b_{2,2}}{b_{2,1}} \tag{2}$$

NDI represents the ratio of intra- and inter-specific competition. If this ratio exceeds one, intra-specific exceeds inter-specific competition, indicating there is niche differentiation between the two varieties.

Results and discussion

Grain yield and yield components

Yields in the pure stands (Table 2) clearly show the higher yielding ability of hybrid rice (circa 7 Mg ha^{-1}), compared to that of glutinous rice (circa 3 Mg ha^{-1}). At higher densities of hybrid rice, both, grain yield per hill and number of panicles per hill decreased, resulting from increased intra-varietal competition. However, grain yield at the highest stand density was significantly higher than that at the lowest stand density, indicating that overall resource capture increased with increasing plant density.

The yields of glutinous rice in pure stand were always higher when there was plant support, but only significantly at the highest plant density (Figure 1). Without plant support, these high density plots also showed the most severe lodging, an observation in agreement with results reported elsewhere (e.g., Bond et al., 2005).

Total grain yield in mixtures was close to the yields obtained in pure stands of hybrid rice and always significantly higher than that in pure stands of glutinous rice. Only at very low planting density of hybrid rice, was total grain yield lower than in the best performing pure stands of hybrid rice. For both, hybrid and glutinous rice, grain yield per hill and number of panicles per hill in the mixtures were identical to those in pure stands at similar total row density. This type of comparison was already proposed by Willey and Osiru (1972), and the results indicate that, on a row basis, both varieties experienced intra- and inter-varietal competition in a similar manner. Two exceptions were found for hybrid rice, where grain yields per hill in mixtures (treatments 5 and 8)

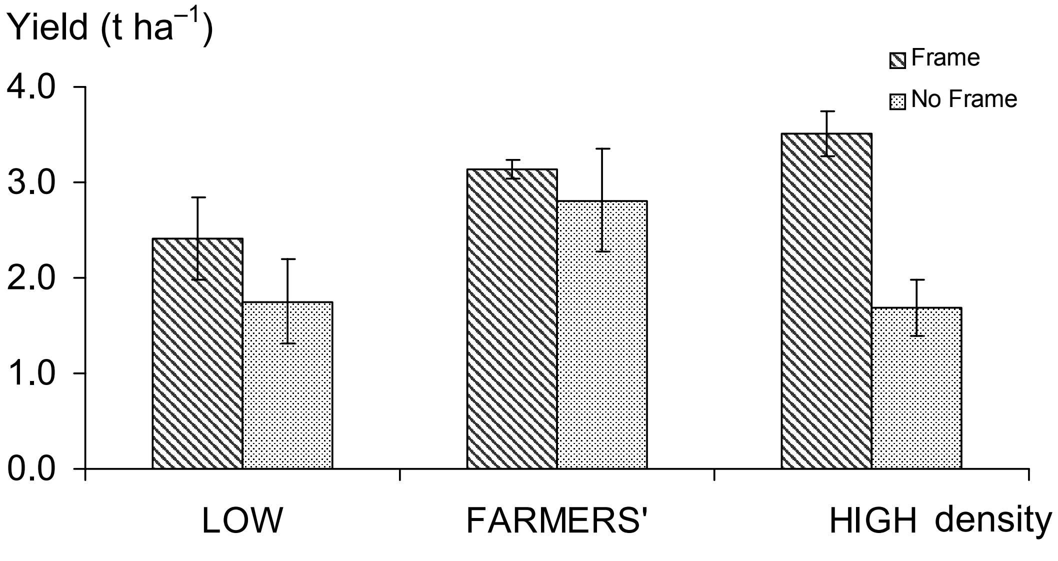

Figure 1. Grain yield of glutinous rice with and without plant support at three plant densities (low = 11.1 hills m^{-2}; farmers = 14.8 hill m^{-2}; high = 22.2 hills m^{-2}).

were significantly higher than those in the pure stands with identical total row density (treatments 3 and 4). These results indicate that, in these situations, hybrid rice experienced a synergistic effect in the mixed planting.

Of the yield components, only the number of panicles per hill was significantly affected by treatment. For both varieties, neither number of grains per panicle nor 1000-grain weight were affected. Differences in yield components among treatments refer to differences in level of competitive stress. As in the course of the development of the rice crop the various yield components are consecutively initiated, differences in a specific yield component form a reliable indication of the developmental phase during which the level of stress was different (e.g., Matsushima, 1970; Yoshida, 1981). The observed pattern suggests that, between the treatments, the relative competitive pressure on the plants was only different during the tillering phase. In this period, the plants adjusted to the available space by producing a number of tillers and panicles per plant that was inversely correlated to the treatments' overall population density. The similar number of grains per panicle and the stable 1000-grain weight indicate that, in the later development stages, the competitive stress experienced in the different treatments was largely identical. This holds for both, the hybrid and the glutinous variety.

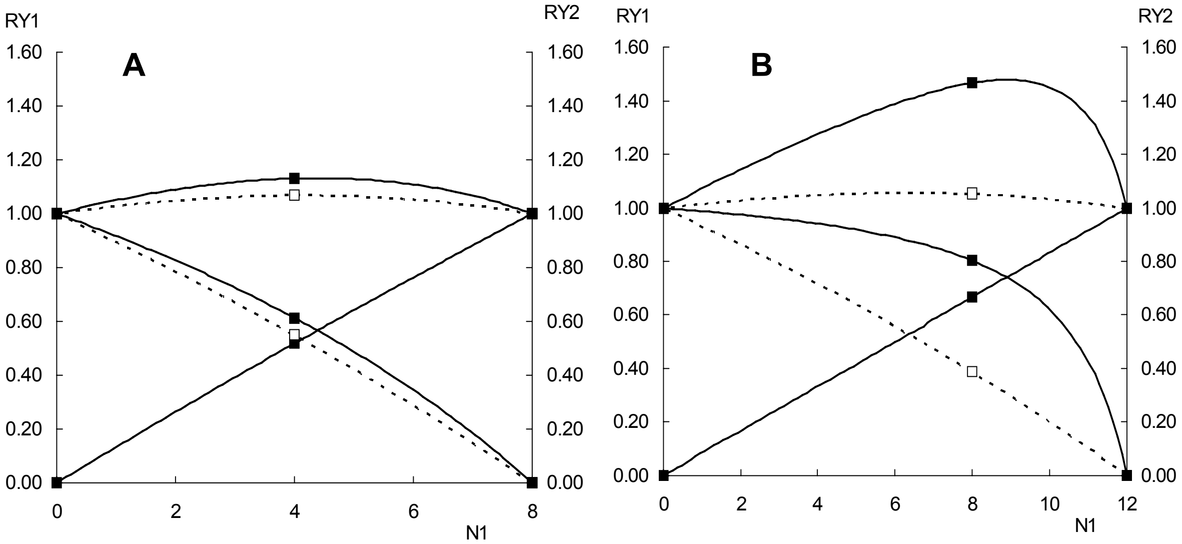

Figure 2. Replacement diagrams of mixed rice systems at farmers' density (A) and at high density (B). Relative yield of glutinous rice was based on pure stands either in the absence (solid line) or in the presence (broken line) of a height-adjustable metal frame for plant support. Density (N1) refers to the number of rows out of a total of 12 planted with hybrid rice.

Replacement diagrams

Figure 2 shows the replacement diagrams at farmers' density (A) and at high plant density (B) for situations where plant support for pure stands of glutinous rice was either absent or present. Plant density in these cases was represented by the number of rows occupied by a specific variety. At farmers' density, RYT was slightly greater than 1 and a marginal difference was observed for the situation with and without plant support. At high plant density, RYT in the mixture attained a value of 1.47, with the pure stand of glutinous rice without plant support as the reference. Yield of the pure stand in this situation was extremely low, because of lodging, and consequently relative yield of glutinous rice in the mixture, where the hybrid rice 'supports' the glutinous rice, was high, resulting in an RYT-value exceeding one. If, on the other hand, the pure stand with plant support was used as reference an RYT of one was retained.

Combining the results of both replacement series does not provide evidence for resource complementarity between both varieties. The high RYT obtained at high plant density resulted from prevention of lodging of the glutinous rice, through the presence of the (shorter) lodging-resistant hybrid rice. Sobkowicz and Tendziagolska (2005) observed a similar phenomenon in mixtures of oats and wheat. In addition, the relative yield of both varieties in the mixture was proportional to their contribution to the overall plant density of the mixture. This is reflected in the shape of the lines that represent the relative yield of each variety in the mixture. The nearly straight lines indicate that, on a row basis, both varieties were about equally competitive.

Regression analysis

Table 3 shows the estimates of the intra-and inter-varietal competition coefficients for the hybrid and glutinous rice variety on a per hill basis. Estimates for the coefficients $b_{1,0}$ and $b_{1,1}$ in Equation 1, representing the inverse of the maximum grain yield per individual hill and per m^2, respectively, were clearly lower for the hybrid variety than for the glutinous variety (Table 3), reflecting its higher yielding ability. The ratios of intra- and intervarietal competition ($b_{1,1}/b_{1,2}$ and $b_{2,2}/b_{2,1}$) both reveal that, on a per hill basis, glutinous rice was more competitive than hybrid rice. For hybrid rice, a hill of glutinous rice exerted a 1.6 ($\approx$ 1.0/0.616) times stronger competitive pressure than a hill of hybrid rice. For glutinous rice, a hill of glutinous rice was nearly 2.3 times as competitive as a hill of hybrid rice. Combining these values, on average the twice higher competitive ability of glutinous rice on a per hill basis with the twice lower hill density of this rice in the row, results again in the observation that, on a per row basis, both varieties were about equally competitive.

Table 3. Estimates of the parameters of the hyperbolic function describing the relation between crop yield and hill density of hybrid and glutinous rice varieties.

	Hybrid rice			Glutinous rice	
	Estimate	SE		Estimate	SE
$b_{1,0}$	0.00715	0.00407	$b_{2,0}$	0.0205	0.0111
$b_{1,1}$	0.00121	0.00015	$b_{2,2}$	0.00182	0.00043
$b_{1,2}$	0.00196	0.00026	$b_{2,1}$	0.00082	0.00014
$b_{1,1} / b_{1,2}$	0.616	0.021	$b_{2,2} / b_{2,1}$	2.28	0.63

NDI, the ratio between the intra- and inter-varietal competition coefficients, yielded a value of 1.41 (±0.43 SEM), implying that in the varietal mixture, intra-varietal competition was slightly, though not significantly, stronger than inter-varietal competition. An NDI value larger than one indicates niche differentiation between the two varieties (Spitters, 1983), which implies that the mixture either captures more resources than the respective pure stands, or utilizes these resources in a more efficient way (Trenbath, 1986). The benefit is however marginal, as an *NDI* of 1.4 corresponds to a yield advantage of about 5%.

Conclusions

Mixtures of glutinous and hybrid rice have been reported to result in spectacular increases in rice grain yield, because of their suppressing effect on the devastating rice blast disease (Zhu et al., 2000). Apart from disease suppression, many additional advantages have been reported for variety mixtures and other intercropping systems (e.g., Vandermeer, 1989). Results of the current experiment revealed that in these rice varietal mixtures, yield advantage resulting from resource complementarity was only marginal. In contrast, prevention of lodging of the tall glutinous rice by the lodging-resistant hybrid rice was identified as an important additional advantage.

CHAPTER 3

Adoption of mixture planting for biodiversity: Its impact on pest management and farmer's income[1]

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Abstract

This chapter presents an overview of the technology adoption and diffusion of mixture planting in Yunnan Province, promoted by a China-IRRI collaborative research project, and assesses its impact on pest management and farmers' income. One hundred four farmer-adopters of mixture planting in four villages and 30 nonadopters from three villages of Shiping and Jianshui Counties, Honghe Prefecture, were personally interviewed from 12 to 28 July 2000 to generate information on household characteristics, farm management practices, input use, yield, costs, and income. Data were then analysed using 'before and after' and 'with and without' project comparisons to determine the impact of mixture planting.

The rapid adoption of mixture planting can be attributed to a vigorous and systematic scheme implemented by the Yunnan Plateau lighthouse team in collaboration with the local extension agency. Results show that farms under mixtures have a lower incidence of blast disease and farmer-adopters on average spent only US$10.50 ha^{-1} for pesticides, compared with nonadopters' pesticide cost of US$42.92 ha^{-1} in 1999. Farmer-adopters had higher yields in 1999 than in 1996. In comparison with the yield on nonadopters' farms, glutinous rice yield is 84% higher on mixture farms. The yield of hybrid rice was almost the same with 20% less land that was allocated to plant one row of glutinous rice between four rows of

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[1] Adapted from:

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hybrid rice. Overall, the yield was 7% higher and gross return was 14% more since the price of glutinous rice, because of its higher quality, was twice that of hybrid rice. The net gain in farm-operator surplus was estimated at 25%

Farmers' perceptions of the impact of mixture planting in general tend to support the results of the quantitative analyses from this study.

Keywords: Rice blast, mixture planting, biodiversity, glutinous rice, technology adoption and diffusion

Introduction

Modern rice production in Asia has more than doubled since the Green Revolution began in the 1960s (Pingali et al., 1997). Nearly 80% of this increase in production came from the increase in yield caused by the spread of improved modern rice varieties. Because the modern varieties are highly profitable compared with the traditional landraces, their introduction has led to an erosion of cultivar diversity with a large proportion of rice area being allocated to a few varieties (Smale, 2000). The increased intensity of cropping that followed the development of irrigation has increased pest pressure leading to farmers using harmful agrochemicals to control pests (Kenmore, 1980; Rola and Pingali, 1993). Although the modern varieties developed later incorporated host-plant resistance against major insects and diseases, farmers still depend on chemical control for pest management (Heong et al., 1995; Fischer and Cordova, 1998; Rola and Widawsky, 1998).

Pest scientists have been trying to develop environmentally sustainable methods of pest management using natural biological control such as habitat diversity and pest-predator relationships (Yatsutmatsu, 1967; Way and Heong, 1994; Yu et al., 1996; Islam and Heong, 1998). Research has been conducted in developed countries to understand the mechanism of pest control with mixed planting of varieties (Wolfe, 1985; Mundt, 1994; Mundt et al., 1996; Zhu et al., 2000, 2001). This project aimed to apply the scientific knowledge on mixed planting of rice to control the endemic blast disease by growing popular glutinous rice varieties in China through adaptive research and farmer participatory experiments.

Chinese farmers had indigenous knowledge of using mixed planting of varieties for control of diseases. Scientists have built on the farmers' indigenous knowledge to develop the proper ratio of mixtures between traditional glutinous rice and modern hybrid rice and crop management techniques for optimum control of pests and maximized yields, using resources provided by the Asian Development Bank (ADB)-funded project on "Exploiting Biodiversity for Sustainable Pest Management," in partnership with scientists from the International Rice Research Institute (IRRI) and advanced research institutions. Part of the resources is used to train farmers in the modern methods of mixture planting to facilitate dissemination of knowledge about the technology and its transfer to farmers' fields.

This study was initiated to evaluate the impact of the project in terms of the adoption of the technology and its effect on the use of pesticides and farmers' income. Its objectives are:

- To present a historical perspective of how the technology of mixture planting diffused in Yunnan Province;
- To assess the impact of mixture planting on pest management and farmers' income; and
- To estimate the rate of return to investment in the project.

Methodology

One hundred four farmer-adopters and 30 nonadopters from seven villages in Shiping and Jianshui Counties, Honghe Prefecture' were randomly selected and personally interviewed between 12 and 28 July 2000. These two counties represent the areas where the technology of mixture planting was first introduced in 1997.

Twenty-six households each from four villages in Shiping and Jianshui were randomly selected as farmer-adopters. To have a control group for comparison, 10 households each from three villages in the two counties were also selected at random to represent the nonadopters.

A pretested questionnaire was used to generate information on farmers' demographic characteristics, landholding, access to information, aspects of the decision-making process in relation to varietal choice, yield, farm management practices, input use, and income.

Adopters were asked detailed questions about their farming situation or practices before and after the adoption of mixture planting. The 'before' situation refers to the year before 1997, whereas the 'after' situation refers to the 1999 rice-cropping season. Similarly, data from the 1999 cropping season were obtained from nonadopters.

Data from 1996 and 1999 were compared to assess the impact of mixture planting on inputs, labour use, yield, costs, and income of adopters. Likewise, the performance of the nonadopters was analysed in comparison with that of the adopters for 1999.

Secondary data on number of farmers and counties adopting rice mixtures, area under mixtures, as well number of training activities conducted on rice mixtures and trainees were obtained from the Plant Protection County Offices of Yunnan Province.

Results and discussion

Background to the project and the technology

In early 1996, the Entomology and Plant Pathology Division of IRRI submitted to the Asian Development Bank (ADB) a project proposal on using biodiversity for sustainable pest management. While waiting for the Bank's approval, opportunities were explored to involve scientists from developing member countries (DMCs) of ADB, using a 'lighthouse' concept in which sites were selected for their potential to demonstrate impact. Five lighthouse sites representing different ecosystems in four DMCs, the Mekong Delta in Vietnam, Chiang Mai Valley in Thailand, Ilocos Norte in the Philippines, Yangtze Delta and Yunnan Plateau, both in China, were identified.

The IRRI research team visited Yunnan Agricultural University (YAU) in 1996 to check whether YAU would be interested in working on blast as the target pest problem. In 1997, Drs. T.W. Mew and P.S. Teng, IRRI Team Leaders, made a second visit to confirm YAU's participation in the ADB-funded project "Exploiting biodiversity for sustainable rice pest management." Professor Zhu Youyong, who had just returned from his postdoctoral stint in Australia, was designated as the team leader of the lighthouse site because, among the YAU staff, he had the longest experience in working with rice blast.

When the project officially began in April 1997, Dr. Chris Mundt, IRRI visiting scientist, first suggested mixing seeds as a varietal diversification technique. Farmers, however, did not like the idea. An experiment that was almost similar to what was done in 1980–84 by YAU was set up in Baoxiu, Shiping County. Each farmer's field of about 0.067 ha was considered as one plot. The team took three rows and five columns of adjacent plots and planted different varieties in each plot. The result was not very good and disease was severe in plots where susceptible varieties were planted.

At about the same time, another varietal diversification experiment within farmers' fields was conducted in Zhangguizhai, also in Shiping County. The farmers, however, modified the experiment by interplanting one row of glutinous rice for every four rows of *indica* rice. The result was quite remarkable. The mixture of glutinous varieties Huangkenuo or Zinuo with hybrid *indica* rice Shianyou 63 or Shianyou 22 significantly reduced the incidence and severity of rice blast disease.

Little was known about this practice of interplanting, which had been followed by a few farmers in limited areas of Shiping County since 1983, although there was no clear pattern.

After the success in Zhangguizhai, more demonstration areas were set up and more and more farmers got involved. Farmers in Honghe Prefecture readily accepted the technology. They find the technology to be simple and easy to apply, aside from the perceived benefits of obtaining higher yield because of less pest pressure, growing high-quality rice, and increases in their income.

The technology spread so fast that, after the project was launched in 1997, the area under mixture planting continued to expand. From the original 667 ha planted to mixtures in Shiping County in 1997, the area grew to about 1,333 ha in Shiping and Jianshui Counties in 1998.

Factors contributing to technology adoption and diffusion

In July 1999, a field day-cum-workshop was organized to share the results of interplanting glutinous rice with hybrid *indica* rice for blast management. A video clip of the varietal diversification project, which was produced by the Central China Television Network, was shown to more than 150 people who attended the meeting. This helped to further increase the enthusiasm of the participants to adopt mixture planting in their respective areas.

During the meeting, both the local prefecture and county government leaders strongly expressed their interest in the project. The Director of the Agricultural Bureau of Honghe Prefecture proposed that the mixture planting project be included in the Bureau's priority project for year 2000 and urged all 13 counties under the prefecture to target 13,333 ha of rice area to be planted to mixtures.

In September 1999, an agricultural task force was organized to prepare the groundwork to implement mixture planting in the different counties. The counties then involved the township leaders in the implementation of the project. The plant protection stations at the county level were tasked to spearhead the implementation of the technology in their respective areas of responsibility. Some counties even allocated funds, and letters of agreement between the upper and lower government units were signed to ensure a clear understanding of responsibilities among the different units involved.

Because of the commitment and systematic coordination of those involved in the project at different levels of leadership, and the financial support provided by ADB through IRRI and through the Key Phytopathology Laboratory of YAU, the project implementation activities went smoothly.

By mid-May 2000, the entire Honghe Prefecture completed interplanting of 16,667 ha of hybrid and glutinous rice, which was 3,333 ha more than in the original plan.

The training process

At the county level, the first step was to hold a meeting with county government officers including the vice mayor in charge of agriculture, the chief of the county science and technology commission, and chiefs of the plant protection and agro-technology stations. Once support was received from the officers, the next step was to conduct a workshop with technicians in agricultural technology and county plant protection officers. These trained technicians then organized, through village officers, small group discussions among farmers. During planting time, the more skilled farmers in the village took the lead to demonstrate to other farmers the procedure of interplanting glutinous and hybrid rice, with the agrotechnicians as supervisors. In 2000 alone, 286 training courses have been organized in 13 counties of Honghe

Table 1. Number of farmers trained on mixture planting, number of farmers using mixture planting and area planted by county from 1998–2000, Yunnan Province, China. Source: Plant Protection County Offices, Yunnan Province.

Year / County	No. of training activities conducted	No. of farmers trained	No. of farmers using mixtures	Area planted to mixtures (ha)
1998				
Jianshui	2	89	352	13
Shiping	15	593	19,975	799
Total	*17*	*682*	*20,327*	*812*
1999				
Jianshui	22	1,490	48,000	2,006
Shiping	32	1,800	54,300	1,336
Total	*54*	*3,290*	*102,300*	*3,342*
2000[a]				
Gejiu	28	2,286	47,000	1,533
Hekou	5	244	4,000	133
Honghe	13	980	17,000	667
Jianshui	60	6,609	80,000	3,333
Jinping	10	621	23,000	667
Kaiyuan	29	2,538	39,000	1,667
Luchong	9	782	21,000	667
Luxi	11	870	22,000	667
Mile	24	2,145	38,000	1,333
Muzhi	20	1,757	35,000	1,333
Pingbeng	13	783	19,000	667
Shiping	54	5,053	84,000	3,333
Yuanyang	10	694	17,000	667
Total	*286*	*25,362*	*446,000*	*16,667*

[a] Data at May 2000.

Prefecture, with 25,362 farmer-participants (Table 1). The total number of farmers using mixtures had increased from 20,327 in 1998 to 446,000 in 2000 (Table 1). The Chinese government has pledged to provide financial support to continue the training till 2003.

Farm household profile

The average household size was four and the average number of children per couple was 1.76 (Table 2). This indicates that the Chinese policy of one child per family is not effectively followed in the rural areas. Farming is done by relatively less educated people. Most of the farm managers had had formal schooling only up to the primary level (Table 3). The younger generation, however, is better educated, indicating progress made over time in human capital formation. In some farm households, more than 20% of the third children are high school graduates. Whether these more educated children will remain in farming will depend on the productivity of labour and income from farming compared with alternative occupations. The average per capita income was estimated at US$207 for the adopter households and US$204 for the nonadopter households. Rice farming accounted for 30% of the household income. The World Bank defines as poor those households with a per capita income of less than US$1 per day. More than 50% of the farm households' per capita income is less than US$187 per annum with income from rice having a share of 39% (Table 4) Thus, although the basic objective of the project is environmental protection, by reducing farmers' dependence on harmful agrochemicals, the project is well targeted to make an impact on poverty alleviation. Since the project area is among the extremely poverty-stricken areas in China, an increase in productivity and income from the adoption of the technology will make a direct contribution to poverty alleviation.

Table 2. Distribution of households (total number of households = 134) by number of members and by number of children, Yunnan Province, China.

No. of members	Percent of households	No. of children	Percent of households
0		0	6.8
1		1	24.8
2	3.8	2	57.9
3	15.9	3	7.5
4	57.6	4	2.3
5	15.9	5	0.8
6	6.1		
7	0.8		

Table 3. Distribution (%) of household members (total number of households = 134) by educational attainment, Yunnan Province, China.

Educational attainment	Head	Spouse	1st child	2nd child	3rd – 5th child
No schooling	7.5	13.1	8.9	12.2	
Elementary (did not finish)	9.8	12.3	17.1	15.6	
Elementary (finished)	54.1	46.9	28.5	34.4	47.1
High school (did not finish)	13.5	8.5	20.3	15.6	11.8
High school graduate	12.8	16.2	17.9	13.3	23.5
Vocational	2.3	2.3	4.9	5.6	5.9
College (did not finish)		2.3	0.8	2.2	5.9
College graduate			1.6	1.1	5.9

Table 4. Annual per capita income and share of rice income by type of farmer, Yunnan Province, China.

Per capita income (US$)	% of adopters reporting (*n*=104)	% of nonadopters reporting (*n*=30)	Share of income from rice farming (%)
< 187	56	52	39
188–375	35	38	22
376–750	9	10	16
Average income	207	204	

Land-use pattern

The predominant crop is rice with almost all area planted to rice during the winter season. Land is mostly left fallow after rice is harvested until the next season. The other occupations are livestock raising and various nonfarm activities.

The average farm size is 0.23 ha and the area planted to rice is about 0.16 ha (Table 5). The government provides each adult household member with 0.067 ha of land, so the land is fairly equally distributed among rural households.

The average area planted to glutinous rice for adopters (0.03 ha) is three times the size of the nonadopters' area (0.01 ha), whereas the area planted to hybrid rice is slightly smaller for the adopters (0.13 ha) than for the nonadopters (0.15 ha).

Prior knowledge on mixture planting

Three percent of the farmers already knew about mixture planting as early as 1993 (Table 6). According to them, some farmers in Shiping County first observed that interplanting maize with sorghum within the same field reduced the incidence of insect pests and diseases. In the early 1980s, some farmers in the village tried to interplant hybrid *indica* rice with the glutinous rice and the results were positive. The effect was marginal, however, because of random planting and hence the practice did not spread. About 70% of the surveyed farmers first learned about the technology in 1998 when YAU, with support from the Department of Agriculture, conducted farmers' training on mixture planting.

The rate of adoption increased fast among the sample farmers, from 11% in 1997 to 88% in 1999. That farmers like the technology is indicated by the rapid diffusion rate.

Varieties planted

Table 7 lists the major varieties grown by the adopters. Four different varieties of glutinous rice were distinctly named by adopters. Before 1997, Huangkenuo (75%) and Zigu (15%) were the most popular glutinous rice varieties grown. Two years after the adoption of mixture planting, the number of adopters using Huangkenuo increased to 82%, followed by Zigu at 14%. Farmers may have realized that Huangkenuo can yield more than Zigu when interplanted with hybrid rice.

Table 5. Farm size, area under rice, and area planted to glutinous and hybrid rice by type of farmer, Yunnan Province, China.

Item	Adopters (ha) (*n*=104)	Nonadopters (ha) (*n*=30)
Farm size	0.23	0.22
Area planted to rice	0.16	0.16
Glutinous	0.03	0.01
Hybrid	0.13	0.15

Table 6. Year when farmer-adopters learned about mixture planting and actual year of adoption, Yunnan Province, China.

Year when learned about mixture planting	Percent of farmers	Source of information[a] (%)			Year when adopted mixture planting	Percent of farmers
		PPS	DA	Co-farmer/ relatives		
Before 1996	2.9	33.3	33.3	33.3	Before 1996	2.9
1997	26.92	10.7	82.1	7.1	1997	10.6
1998	70.2	5.5	93.2	1.4	1998	86.5

[a] PPS = Plant Protection Station; DA = Department of Agriculture.

Table 7. Distribution of adopters (n=104) by name of variety planted before (1996) and after (1999) adoption of mixture planting, Yunnan Province, China.

Glutinous rice	Percent reporting		Hybrid rice	Percent reporting	
	1996	1999		1996	1999
Ai'jiaonuo	5.0	-	Ganyou 63	0.5	0.5
Baikenuo	-	1.0	Guicao	1.0	-
Huangkenuo	75.0	82.0	Shanyou 63	42.3	20.2
Qitougu	5.0	2.0	Siyou 22	-	0.5
Zigu	15.0	14.0	Siyou 63	6.3	28.9

Table 8. Distribution of nonadopters (n=30) by name of variety planted, Yunnan Province, China.

Glutinous rice	Percent of farmers reporting	Hybrid rice	Percent of farmers reporting
Duiduino	16.7	Feyou 63	3.3
Zajiano	16.7	Shanyou 63	63.3
Huangkenuo	66.7	Teiyou 63	3.3
		Yungan14	3.3
		Ganyou 63	3.3
		Siyou 63	16.7
		Siyou 22	3.3
		Others	3.3

For hybrid rice, more than 40% of the adopters planted Shanyou 63 in 1996 and 6.3% reported using Siyou 63. In 1999, the distribution of adopters using Shanyou 63 and Siyou 63 was about the same.

Among nonadopters, Huangkenuo and Shanyou 63 were, respectively, the most popular varieties of glutinous and hybrid rice grown (Table 8).

Sources of seeds

Table 9 lists the different sources of glutinous and hybrid rice. From the data, it can be gleaned that the government has developed an infrastructure for hybrid seed production and distribution. Seeds of hybrid rice for both farm types come from the Department of Agriculture. However, farmers depend on a local network of farmer-to-farmer exchange of seeds for the traditional glutinous rice, because of the absence of formal institutions for the production and distribution of seeds for the traditional varieties.

A majority of the adopters are more than satisfied with the performance of their chosen varieties, whether glutinous or hybrid rice (Table 10). Among the nonadopters, the ratings of glutinous rice are equally distributed among excellent, very good and good. It was rated poor by 13% of the farmers within that group. Hybrid rice likewise is rated either very good or good.

Criteria for varietal choice

Farmers have multiple responses when asked about their criteria in choosing rice varieties. Based on the number of responses obtained, we ranked these criteria in terms of the three most important ones (Table 11). Among adopters, the number one criterion for their choice of glutinous rice is its good eating quality. The sticky glutinous rice serves as a social symbol for the ordinary Chinese farmers. Sticky rice confections are served during Chinese festivals to symbolize closeness among members of the Chinese family. Practically every festival or family occasion is celebrated by serving specialty dishes made from glutinous rice. Aside from the eating quality, farmers choose to grow glutinous rice because it has a high yield, commands a higher price in the market, has a low fertilizer requirement, and is resistant to lodging. The latter may have been the result of interplanting glutinous rice with hybrid rice.

On the other hand, farmers' first major consideration in the choice of hybrid rice is the potential high yield of the variety. Disease resistance ranks second, followed by low fertilizer requirement.

A similar ranking of reasons is observed among nonadopters, except that for hybrid rice, good eating quality is mentioned as the second reason (Table 12).

Table 9. Distribution of farmers by source of variety, Yunnan Province, China.

Source of variety	Adopters[a] (*n*=104)		Nonadopters (*n*=30)	
	GR	HR	GR	HR
Department of Agriculture	8	97	17	97
Own produce/previous harvest	17	1		
Other farmers	75	2	83	3

[a] GR = glutinous rice, HR = hybrid rice.

Table 10. Distribution of farmers according to the results of varietal use, Yunnan Province, China.

Result of usage	Adopters[a] (*n*=104)		Nonadopters (*n*=30)	
	GR	HR	GR	HR
Excellent	17	8	29	10
Very good	78	77	29	42
Good	4	14	29	48
Poor	0	1	13	0

[a] GR = glutinous rice, HR = hybrid rice.

Table 11. Ranking of reasons for varietal use, adopters, Yunnan Province, China[a].

Reason for use	Glutinous rice			Hybrid rice		
	1st	2nd	3rd	1st	2nd	3rd
High yield	23	-	-	99	-	-
Good eating quality	66	9	-	3	11	-
High grain recovery	1	2	-	1	6	-
Insect resistance	-	6	-	-	-	-
Disease resistance	-	-	-	-	29	5
Submergence resistance	-	-	-	-	1	6
Low requirement of fertilizers	-	-	5	-	2	14
Marketable	-	7	1	-	-	-
High price	-	10	1	-	-	-
Lodging resistance	8	2	4	1	-	1

[a] Ranking is based on the number reporting and may not add up to 104.

Table 12. Ranking of reasons for varietal use, nonadopters, Yunnan Province, China[a].

Reason for use	Glutinous Rice			Hybrid Rice		
	1st	2nd	3rd	1st	2nd	3rd
High yield	2	-	-	29	-	-
Good eating quality	3	2	-	-	16	-
Disease resistance	-	-	-	-	12	3
Low fertilizer requirement	-	-	-	-	-	10
Marketable	1	2	-	-	-	-

[a] Ranking is based on the number reporting and may not add up to 30.

Table 13. Mean yield of glutinous and hybrid rice by type of farmer, Yunnan Province, China. Data of adopters refer to either before (1996) or after (1999) adoption.

Rice yield	Adopters (*n*=104)		Nonadopters (*n*=30)
(t ha^{-1})	1996	1999	1999
Glutinous rice[a]	1.5	2.0	1.1
Hybrid rice	8.4	8.4	8.6

[a] Differences between yields of adopters in 1996 and 1999 and between yields of adopters and nonadopters for glutinous rice in 1999 are highly significant at 1% level of probability.

Effect of mixture planting on yield

Table 13 presents the average yields of glutinous and hybrid rice. The glutinous rice yield of adopters was 34% higher in 1999 than in 1996, averaging 2 t ha^{-1}. This yield is about 80% higher than the average yield obtained by nonadopters in 1999. The differences in glutinous rice yields between years and between adopters and nonadopters are significant (1% probability). On average, the yield of hybrid rice for adopters in 1999 was the same as in 1996, although some land had been shifted to glutinous rice to accommodate mixed planting. The yield for nonadopter farms, where the entire plot was planted with hybrid rice, was 8.6 t ha^{-1}, only 2% higher than that for the adopter farms. The average yield when both varieties are taken into account was about 7% higher for the adopter farms than for the nonadopters.

Mean level of input use

Table 14 reports the mean level of input use in both physical quantities and costs. The major differences in input use by adopters and nonadopters were in seeds, pesticides, and labour used for transplanting and harvesting. The seed rate was about 10% higher for nonadopters because of the higher seed rates used for hybrid rice. There was no difference in the use of chemical fertilizers.

Mixture planting has obviously affected the level of pesticide use of the adopters. Because of less incidence of blast, adopters' pesticide expense decreases by 44% when they interplant glutinous rice, that is highly susceptible to blast, with hybrid rice. The average number of sprays was only 0.7 for the adopters versus 3.5 for the nonadopters. The nonadopters spent US$42.92 ha^{-1} on pesticides compared with only US$10.50 ha^{-1} for the adopters, i.e., net savings of US$32.42 ha^{-1} from adoption of the technology. The reduction in the number of sprays also brought about additional health benefits, since farmers were less exposed to toxic pesticides.

For most farm labour operations, the nonadopters' labour use was always higher than that of the adopters in both years, except for labour for transplanting and harvesting. As expected, labour use for seedbed preparation, transplanting, and harvesting was higher in 1999 than in 1996 among adopters. Labour for pesticide application, however, was 0.75 man-day lower for adopters in 1999. The additional labour requirement for mixed planting was due to separate transplanting and harvesting of the glutinous rice, which matures about two weeks later than hybrid rice.

Costs and returns analysis

To assess the impact of mixture planting on farmers' income, the costs and returns of farm production were estimated (Table 15). Because of the higher yields from glutinous rice, which commands a higher price in the market, the gross value of production realized by the adopters is much higher than that of the nonadopters. Adopters gained an additional US$143.98 ha^{-1} compared with the 1996 level.

Contrary to expectations that mixture planting requires more seeds, adopters spent

Table 14. Mean level of input use per hectare by type of farmer, Yunnan Province, China. Data of adopters refer to either before (1996) or after (1999) adoption.

Inputs	Adopters (*n*=104)		Nonadopters (*n*=30)
	1996	1999	1999
Seed			
Quantity (kg)			
Glutinous rice	5.4	4.4	3.2
Hybrid rice	35.0	32.0	37.1
Cost (US$)			
Glutinous rice	0.08	0.07	0.28
Hybrid rice	4.60	3.99	4.66
Fertilizer			
Quantity (kg)	1,433	1,433	1,475
Cost (US$)	11.18	11.18	12.03
Pesticides			
Cost (US$)	18.58	10.50	42.92
No. of sprays	2	1	3
Labour (man-days)			
Seedbed preparation	8.85	9.15	23.85
Land preparation	13.80	14.10	23.70
Transplanting	62.70	70.20	59.70
Fertilizer application	6.60	6.60	16.05
Pesticide application	3.60	2.85	20.25
Weeding	3.05	13.35	16.05
Harvesting	71.10	85.20	78.60

US\$9.36 ha^{-1} less for seeds in 1999. This may be due to more efficient use of seeds by farmers when they follow the straight row planting of both glutinous and hybrid rice. Adopters' seed expense was US\$9.52 ha^{-1} lower than that of the nonadopters.

There was also a substantial reduction of US\$8.08 ha^{-1} in pesticide costs among adopters in 1999. Nonadopters spent US\$32.42 ha^{-1} more on pesticides than did the adopters.

Although additional labour costs are incurred for both transplanting and harvesting, the savings from pesticides and seeds and the higher price of glutinous rice are more than enough to compensate for the increased labour costs. Thus, we see from Table 15 that, in 1999, the net returns above cash costs obtained by adopters are US\$162 ha^{-1} higher than in 1996 and US\$320 higher than those of the nonadopters.

Table 15. Costs per ha (US\$ ha^{-1}) and returns by type of farmer and by year, Yunnan Province, China. Data of adopters refer to either before (1996) or after (1999) adoption.

Item	Adopters (*n*=104)		Nonadopters (*n*=30)
	1996	1999	1999
Gross value of production	2,153.85	2,297.83	2,016.66
Price kg^{-1} of			
Glutinous rice	0.50	0.36	0.38
Hybrid rice	0.17	0.19	0.19
Costs of production	692.96	674.62	713.92
Seeds			
Glutinous rice	1.48	1.09	1.89
Hybrid rice	69.06	59.70	69.22
Fertilizer	167.70	167.70	180.52
Pesticides	18.58	10.50	42.92
Hired labour	436.14	435.75	419.36
Net returns above cash costs	1,460.62	1,623.21	1,302.73

Impact perceived by farmers

Table 16 shows the impact of mixture planting based on farmers' perceptions. A majority of the farmers thought that there was a significant increase in labour use for seedbed preparation and transplanting (63%) and harvesting (75%) as a result of adopting mixture planting. Farmers also perceived that this technology required more seeds (54%), but lower pesticide costs (87%) because of less incidence of blast disease (90%).

Now that farmers are able to plant more rice varieties (86%), genetic diversity is also improved. However, despite the ecological soundness of reduced pesticide use, farmers do not seem to associate it with improvements in soil and water quality, nor with reduced mortality of fish and other aquatic species in rice fields.

Most of the farmers (94%) perceived that mixture planting resulted in higher yields. As yield improved, there was an adequate supply of rice (81%) for home consumption. Almost all farmers reported that adoption of mixture planting improved income (97%) and quality of life (98%).

Economic impact of the project

As noted from the above findings, this technology adoption had the following effects:

- Reduced pesticide use.
- Increased yield from reduction of crop losses from pests and lodging.
- Increased production costs due to higher labour use in planting and harvesting.

Table 16. Farmers' (*n*=104) perceptions (%) of the impact of adoption of mixture planting, Yunnan Province, China.

Impact indicator	Increase	Decrease	No change
Labour use			
Land preparation	6		94
Seedbed and transplanting	63		37
Crop care	6	3	91
Harvesting	75	1	24
Input use			
Seeds	54	5	41
Fertilizer		1	99
Pesticides	1	87	12
Pest problems			
Insects	2	5	93
Diseases	4	90	6
Weeds		2	98
Others	1		99
No. of varieties planted	86		14
Soil quality	1		99
Water quality	2	1	97
Livestock mortality			100
Yield	94		6
Rice adequacy	81		19
Income	97	1	2
Quality of life	98	1	1

Cost savings from reduction in pest pressure

The most direct benefit from mixture planting is the reduction in pest pressure, that is, blast disease, which implies some savings in the use of pesticides and labour for spraying pesticides. The average number of sprays was 3.5 for the nonadopters compared with only 0.7 for the adopters, which would have a positive effect on health. It has been documented that several diseases are caused by exposure to harmful chemicals during spraying (Rola and Pingali, 1993).

Because of the reduced incidence and severity of blast disease, adopters spent only US\$10.50 ha^{-1} for pesticides, compared with nonadopters' expenditure of US\$42.92 ha^{-1}. There is also substantial savings in the amount of labour used for spraying pesticides. Comparing the costs incurred by both adopters and nonadopters for pesticides and labour, we estimate that the gains from adopting the technology are about US$72 ha^{-1} (Table 17).

Yield gains from reduction in losses

In general, 25–40% of the yield of monocropped glutinous rice is lost due to blast disease (Zhu, 2000, 2001). The crop also suffers from lodging when there is strong wind because of weak stems and taller plants. The method of interplanting one row of glutinous rice with four to six rows of hybrid rice as a form of varietal diversification helps control blast disease and lodging of the glutinous rice plants. In Table 18, we see that, for nonadopters, only 6% of the area is planted to glutinous rice compared with 19% for adopters.

On mixture farms, the yield of glutinous rice has increased by 82% following adoption of mixture planting. This figure is much higher than the 25–40% yield loss from blast. However, the yield of hybrid rice has decreased by about 2%. The combined yield of glutinous and hybrid rice was 10.4 t ha^{-1} for adopters versus 9.7 t ha^{-1} for nonadopters. Thus, the overall yield gain from adopting the technology was about 7%.

Table 17. Cost savings from reduction in pest pressure, Yunnan Province, China.

Item	Adopters (*n*=104)	Nonadopters (*n*=30)
Number of sprays	0.7	3.5
Cost of pesticides (US$ ha^{-1})	10.50	42.92
Labour for pesticide application (d ha^{-1})	2.85	20.25
Imputed cost of labour (US$ ha^{-1})	6.49	46.10
Total cost (US$ ha^{-1})	16.99	89.02
Financial benefit (US$ ha^{-1})	72.03	

Table 18. Yield gains from reduction in losses from blast disease and lodging, Yunnan Province, China.

Item	Adopters (*n*=104)	Nonadopters (*n*=30)	Percent difference
Percent of rice area under glutinous rice	18.8	6.2	203.2
Rice yield (t ha^{-1})	10.4	9.7	7.2
Glutinous rice	2.0	1.1	81.8
Hybrid rice	8.4	8.6	–2.3
Gross revenue (US$ ha^{-1})	2,298	2,017	13.9
Financial gain (US$ ha^{-1})	281		

Table 19. Benefits to farmers from adopting mixture planting, Yunnan Province, China.

Net benefits	Values
To farmers (US$ ha^{-1})	314
As % of gross revenue	13.9
As % of family income	25.4

The gain in gross revenue is even higher at 14%, since glutinous rice fetches a price almost double that of hybrid rice because of higher grain quality and the use of glutinous rice at social occasions. The gain in gross value of production from adopting the technology is estimated at US$281 ha^{-1}, almost four times higher than the cost savings in pesticides.

Additional labour costs

This technology is not costless, as shown in previous analyses and based on farmers' perceptions. Substantial additional costs are incurred, particularly in two farm operations. One is for transplanting because adopters have to transplant twice. Another is for harvesting because farmers have to harvest the glutinous and hybrid rice separately. The mixture-planting technology requires additional labour of 17.1 d ha^{-1} for transplanting and harvesting and the imputed cost of the additional labour is about US$39 ha^{-1}.

Benefits to farmers from technology adoption

Net income to farmers, after subtracting the additional labour costs of transplanting and harvesting from the value of the two benefits mentioned above, is US$314 ha^{-1} and this is about 14% of the gross revenues from rice cultivation (Table 19).

Farmers' loss of income from reduction in prices of glutinous rice

There is also some expected reduction in farmer-adopters income because, as more glutinous rice is produced, the market price goes down. This will be a cost to the farmers. On the other hand, consumers stand to benefit from lower prices of glutinous rice.

Note that, with the increased production of glutinous rice, the price has gone down from US$487 t^{-1} in 1996 to US$346 t^{-1} in 1999 for the adopters (Table 20). This will be a major constraint later to the large-scale adoption of the technology, as the financial gain is eroded due to lower prices.

Assuming that, in the long run, the price of glutinous rice would decrease to the level of that of hybrid rice, the minimum net gain would still be US$166 ha^{-1}. In the following analysis, this conservative estimate will be used instead of the estimated present net benefits of US$314 ha^{-1} to estimate the rate of return to the project, assuming there will be a price reduction for glutinous rice in the long run.

The rate of adoption of the technology

The rate of technology adoption must also be considered in order to estimate the future time stream of benefits. The technology spread from a mere 812 ha under mixture planting in 1998 to 16,667 ha in 2000 (Table 21). Large-scale training of farmers is one of the technology transfer methods implemented to ensure a fast rate of technology diffusion.

A critical factor that contributed to the fast rate of adoption was the use of local county officials and technicians as trainers. They worked with farmers closely and actively to demonstrate the technology and this helped encourage more farmers to participate. We, therefore, need to account for the cost of extension when calculating the rate of return.

The target area for expansion in 2003 is about 200,000 ha. With this kind of extension in Yunnan Province, it is possible to achieve this target, which is about 25% of the area under rice in Yunnan Province. However, we perceive that the trend in

Table 20. Prices (US$ t^{-1}) of glutinous and hybrid rice, Yunnan Province, China.

Item	Adopters (*n*=104)		Nonadopters (*n*=30)
	1996	1999	1999
Glutinous rice	487	346	366
Hybrid rice	163	184	183

Table 21. Rate of adoption of mixture planting from 1998 to 2000 and target area coverage for 2003, Yunnan Province, China.

Item	1998	1999	2000[a]
No. of farmers in the area where mixed cropping was promoted (000)	144	252	927
Percent of farmer-adopters[b]	14.1	40.6	48.1
No. of farmers trained	682	3,290	25,362
Area planted to mixtures (ha)	812	3,342	16,667

Target area planted to mixtures for 2003	200,000 ha
Total rice area in Yunnan Province	800,000 ha
Rice area under hybrid rice	300,000 ha

[a] Data at May 2000; [b] With reference to number of farmers using mixtures in Table 1.

price of glutinous rice may constrain the diffusion of the technology at this scale unless the provincial government is able to find an export market for the surplus produce. To be on the conservative side, we assume that at full development the technology will spread to 100,000 ha by 2003 and will remain at that level until 2007, when the technology may become obsolete.

Estimated cost of the project

Table 22 presents the total estimated cost of the mixture-planting project in Yunnan from 1997 to 2003. Investments come from three sources: IRRI, the Chinese government, and the local Chinese partners. IRRI substantially increased its level of support to the Yunnan lighthouse site when the project started to make an impact. From US$137,000 in 1997, YAU received and additional US$83,000 in 1999. Similarly, YAU received increased funding support from the Chinese government to expand the area under mixture planting.

Assuming that IRRI will provide US$220,000 each year if a 3-year second phase of the project is approved by ADB, the total investment will be US$357,000 in 2002 and US$146,000 in 2003. These investments are critical for extending the technology.

Table 22. Estimated costs (US$000) of the mixture-planting project, 1997–2003.

Year	Investment from IRRI[a]	Imputed cost of Chinese partner's time	Chinese government contribution	Total
1997	136.6	14.6	-	151.2
1998	136.6	14.6	36.6	187.8
1999	220.0	14.6	91.5	326.1
2000	220.0	14.6	73.2	307.8
2001	220.0	14.6	122.0	356.6
2002	220.0	14.6	122.0	356.6
2003			146.3	146.3

[a] Includes funds from ADB.

Table 23. Benefit-cost ratio of the mixture-planting project, 1997–2007.

Discount rate (%)	Benefit-cost ratio	
	1997–2000	1997–2007
15	2.7	22.0
50	2.0	8.7
100	1.3	7.8

Benefit-cost ratio of the project

The farmers who already adopted the technology will continue to reap the benefits for many years to come until new pest problems make the technology obsolete. We assume 2007 as the terminal year for the continuation of benefits.

The investment in the project has already been recovered in just three years since the project began in 1997 (Table 23). At a 15% discount rate, the benefit-cost ratio is 2.7 for the period 1997–2000. If we take the full time stream of benefits from 1997 to 2007, the project gives a benefit-cost ratio of 22. Even at a 100% discount rate, the benefit-cost ratio will still remain high at 7.8, which means that the actual rate of return on investment is higher than 100%. The internal rate of return from investment in the project (the China component) is estimated at 160%.

Conclusions

Mixture planting has brought several environmental and economic benefits to the farmers in Yunnan Province. The simple technique of interplanting the glutinous rice that is highly susceptible to blast with hybrid *indica* rice has reduced the incidence of blast in Yunnan Province. Farmers have reduced their pesticide use and are now able to grow the high-value glutinous rice. Yields of glutinous rice have also increased and this has brought about higher net income for the farmers. Farmers who are already adopting the technology will continue to reap the benefits for many years until new pests problems arise.

CHAPTER 4

Farmers' perceptions and adoption of rice varietal mixtures in Yunnan Province: A Tobit analysis

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Abstract

The Yunnan experience on rice blast is one of the most successful and publicized examples of genetic diversification for disease suppression in practice. Before 1998, farmers had to spray fungicides 3 to 8 times per cropping season in order to successfully grow a crop of glutinous or sticky rice. An IRRI-led team of scientists, working in Yunnan Province, China, found a way to use biodiversity to control rice blast disease and minimize pesticide use. While the epidemiological soundness of cultivar mixtures to suppress disease epidemics has long been scientifically demonstrated, the recent dramatic increase in farmers' adoption of this practice is phenomenal. From a mere 15 ha in 1997, adoption increased to 551,334 ha in 2003. A Tobit model was used to determine the major factors that conditioned farmers' decisions to adopt rice varietal mixtures in Yunnan. Results show that contact with extension workers and farmers' perception of the technology-specific attributes of the rice varietal mixtures were the major factors determining adoption probability and use intensity.

Keywords: Rice blast, biodiversity, innovation

Introduction

Adoption of technological innovations in agriculture has attracted considerable attention among development economists, because the majority of the population of less developed countries derives its livelihood from agricultural production and because new technology seems to offer an opportunity to substantially increase production and income (Feder et al., 1985). However, in many cases, introduction of new technologies has met with only partial success, as expressed in observed rates of adoption. As past experience shows, immediate and uniform adoption is quite rare. Some innovations have been well received, while others have been adopted by only a very small group of farmers (Rogers, 1995).

Since the classic work of Rogers (1962), efforts to identify the determinants of innovation diffusion and adoption continue. Two major groups of paradigms for explaining adoption decisions can be found in literature: the innovation-diffusion, and the economic constraint paradigms. The innovation-diffusion model follows Rogers' analysis of diffusion and holds that access to information about an innovation is the key factor in determining adoption decisions, while the economic constraint model (Aikens et al., 1975) contends that economic constraints, reflected in asymmetrical distribution patterns of resource endowments, are the major determinants of observed adoption behaviour. A third paradigm, the adopter perception paradigm (Kivlin and Fliegel, 1967), is the least quantitatively developed in literature. This paradigm suggests that the perceived attributes of innovations condition adoption behaviour. Consequently, adoption of technologies by farmers may reflect rational decision-making based on farmers' perceptions of their appropriateness.

One typical example of immediate and large-scale adoption of technology is that of the rice varietal mixtures in Yunnan Province, China (Revilla et al., 2001, 2003; Leung et al., 2003; Chapters 3 and 6). Rice blast, caused by the fungal pathogen *Magnaporthe grisea*, is the main destructive disease of rice in Yunnan. The wet, cool climate of the province is highly favourable for the development of rice blast epidemics. Farmers commonly make multiple foliar fungicide applications to control blast (Zhu et al., 2000).

With the incorporation of resistance genes, rice blast is no longer a serious problem in widely grown hybrid *indica* rice and normally does not cause significant yield loss (Shen and Lin, 1994, 1996). When a new race or pathotype evolves that has overcome the resistance, the variety is replaced by a new variety with a new resistance gene. However, the disease has remained a serious problem in glutinous rice and other traditional high-quality rice varieties, because of relatively little effort to improve these varieties through resistance breeding.

Before 1998, 98% of the rice fields in Yunnan were sown with monocultures of the hybrid rice varieties Shanyou 63 and Shanyou 22 (Zhu et al., 2000). The preferred glutinous rice varieties were planted in small areas because of their low yield potential and susceptibility to blast in this environment.

In what the New York Times described as a "stunning success" and "one of the largest agricultural experiments ever", an IRRI-led team of scientists working in Yunnan found a way to use biodiversity to improve control of rice blast, a disease that can cost the rice industry millions of dollars annually. By planting different types of rice alongside each other, the scientists found they could almost completely control the spread of the disease, resulting in reduced pesticide applications. Known in scientific circles as exploiting biodiversity for sustainable pest management, the idea is not new to many farmers. Some farmers in Yunnan already had indigenous knowledge of planting mixtures of varieties for controlling diseases, even before the project was launched. The idea, however, did not spread because the technology was not sufficiently developed and farmers did not know what to mix and how to mix the varieties. Their "indigenous knowledge system" was clearly different from the "scientific knowledge system" and yet much was gained in the interaction of the two (Chambers and Ghildyal, 1985; Chambers and Jiggins, 1987; Scoones and Thompson, 1994; Sumberg and Okali, 1997). Scientists have built on farmers' indigenous knowledge to develop the appropriate ratio and geometry of interplanting the traditional glutinous rice and modern hybrid rice varieties, and crop management techniques for optimum control of pests and maximum yields.

The interplanting system provides a mechanism for managing diseases through genetic diversification of rice cultivars on one hand, and offers a means for on farm germplasm conservation, on the other. The initial success, resulting from the demonstration plots, soon encouraged more farmers to practice the diversification scheme. This chapter first puts forward the key elements of the technology diffusion process in Yunnan. It then uses a Tobit analysis to examine which farmers were most prone to adoption, and how farmers' perception of technology characteristics affected their decision to adopt rice varietal mixtures.

The technology diffusion process in Yunnan

To scale up the rice mixtures to more farmers, it was necessary to understand how the extension system works in Yunnan Province. We designed an approach based on three general principles or considerations. First, there must be a demand for the technology or innovation. Second, farmers must be involved in the process of diffusion. Third, the provincial and local government units (LGU) must be convinced of the beneficial impact of the technology.

As part of the process of technology diffusion, we can summarize our experience in Yunnan in the steps described below. These different steps might help explain why the technology diffused from first introduction to widespread use in a few years (Rogers, 1995). This was not only because of China's socio-political structure, but also because of a carefully thought-through process, based on some understanding of the local culture and cultivated on human relations.

Our approach of varietal diversification through interplanting follows the oriental systems approach proposed by Gu and Zhu (2000). Figure 1 outlines the key elements of our process of technology diffusion in Yunnan Province.

1. *Understanding farmer desires or needs*. Initial problem diagnosis and environmental (biophysical, social, economic, political) characterization are essential to technology diffusion or upscaling of technology**.** Consultations with several key informants and farmers were conducted in order to understand the needs of farmers**.** It was established that there was a need to control rice blast to produce a decent crop of glutinous rice.
2. *Investigating conditions*. To assess existing conditions in the field, field surveys and personal interviews with farmers and extension personnel were conducted. As Castillo (2001) puts it, "being involved with the field conditions and practicalities enables us to learn not only with our minds but also with our hearts".
3. *Formulating objectives*. Can we produce more rice and control blast by interplanting glutinous rice with hybrid rice? Will the yield of hybrid rice be reduced when interplanted with glutinous rice? With the objective of answering these questions, we then prioritized the problems and designed the spatial patterns to achieve a feasible solution. On the basis of information on conditions**,** full and open discussions among concerned stakeholders (scientists, government officials in charge of agriculture, and science and technology, plant protection and extension personnel, village leaders, and farmers) were held to identify the constraints and formulate objectives based on farmers' needs.
4. *Creating models*. After formulating the objectives and knowing the field conditions and other concerns, design and testing of technology through on-farm experiments and demonstration trials took place. The team of Yunnan Agricultural University (YAU)-IRRI scientists established experiments involving farmers and LGU officers to establish the ratio of mixtures that reduces blast incidence and leads to higher farm productivity.
5. *Coordinating relations*. Plans for the expansion of the technology adoption and diffusion were developed during the field day-cum-workshop in July 1999, which were instrumental in the systematic execution of activities by and among stakeholders at different levels after demonstrating the potential of the interplanting technology. During the meeting, both, the local prefecture and county government

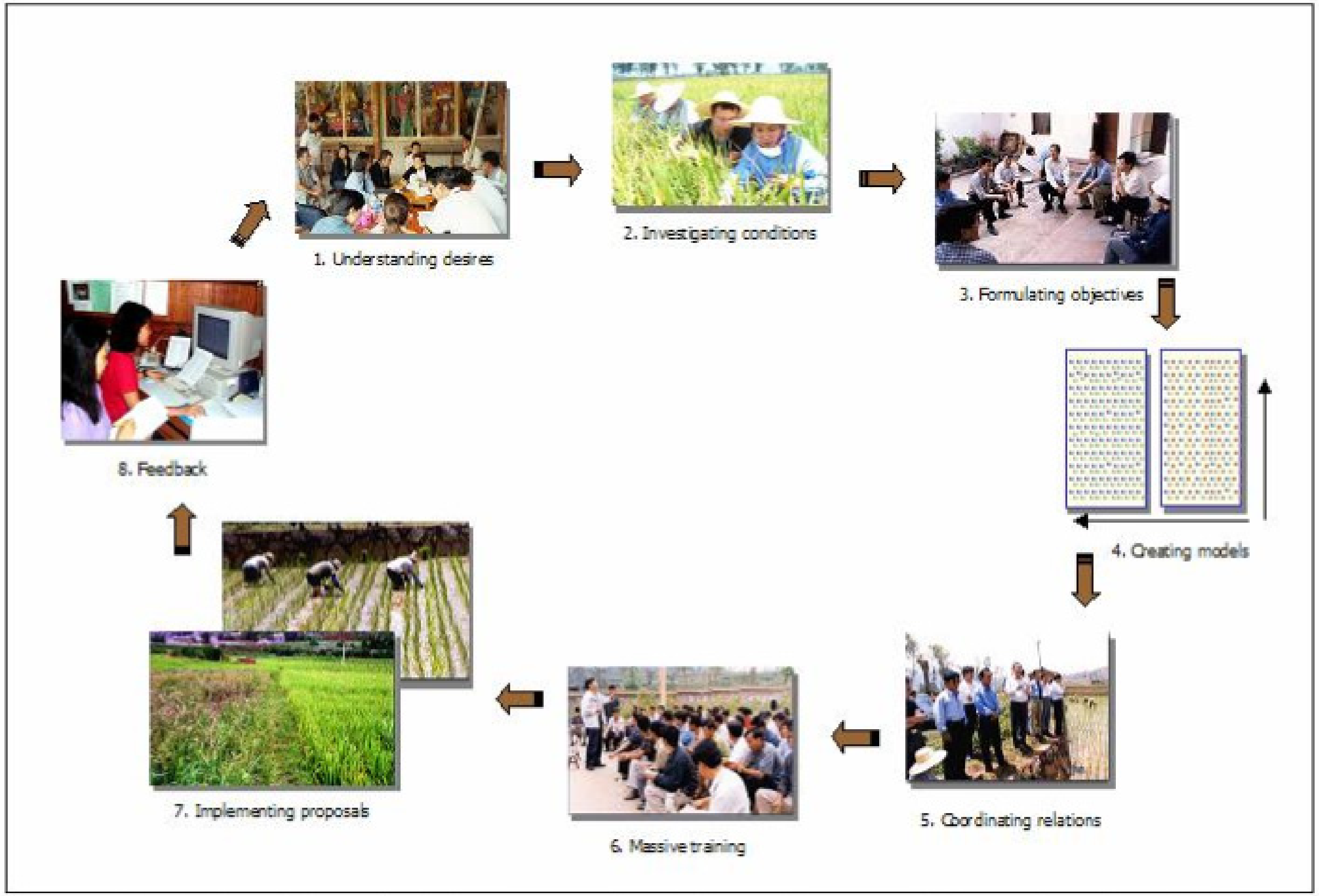

Figure 1. Key elements of the process of technology diffusion in Yunnan Province, China.

leaders strongly expressed their interest in the project. The Director of the Agricultural Bureau of Hong He Prefecture proposed that the mixture planting project be included in the Bureau's priority project for the year 2000 and urged all 13 counties under the prefecture to target 13,333 ha of rice area to be planted to mixtures.

Nurturing relationships among the social actors involved in the project facilitated smooth implementation in almost all of the counties where the technology was introduced. Farmers were not only convinced that the system worked, but also felt the commitment of the technology or project implementers and, therefore, trust easily developed between the change agents and farmers in the course of the diffusion process.

6. *Conducting large-scale farmers' training*. Substantial resources were then invested in on-farm training to transfer the technology to more farmers. This was critical in the large-scale training of farmers. Meetings with and training of farmers took place even during the evenings. Farmers were taught about the concepts, and together with the agro-technicians and village leaders, they were given actual hands-on training on rice varietal interplanting. To make the process more efficient and effective, LGU at all levels, with the participation of personnel of agricultural research and service organizations were involved.
7. *Implementing proposals*. Dissemination of technology in similar recommendation domains was discussed with the policy makers and their buy-in contributed to the rapid technology adoption and diffusion. In implementing the technology of rice varietal mixtures, the emphasis was on practice rather than on theory. This process element is complementary to the massive on-farm training. Thus, the concept of rice varietal mixtures found its practical application in the field, as evidenced by the changing landscape of rice production, not only in Yunnan, but also, through spill-over effects, in 10 other provinces in China.
8. *Getting feedback*. Evaluation of adoption of the technology and its impact on family welfare helped sustain its usefulness and supported its further improvement. The project team also felt the relevance of an effective feedback mechanism among farmers, extension agents, and research systems. This was made possible by conducting interviews and communicating the feedback to concerned stakeholders to improve the technology and also the process of technology diffusion.

These eight process elements constituted a project cycle of design, adoption, and diffusion of rice varietal mixtures in farmers' fields.

Methodology

Data and data collection

Data for this study were obtained from a survey of 260 households in Shiping, Jianshui, Mile Kaiyuan, and Yuxi Counties of Yunnan Province, conducted in July and October 2000. Ten households each from 20 adopter villages and six nonadopter villages were randomly selected and the head of the household was personally interviewed, using a semi-structured questionnaire. Adopter villages refer to villages where rice varietal experiments within farmers' fields had been conducted and farmers were trained by extension workers. Nonadopter villages were located in areas with much less exposure to extension workers. For the final analysis, one nonadopter was dropped from the sample due to incomplete data. For this study, both farmer-specific attributes (e.g., farm experience, education, household size and contact with extension workers) and perceived technology-specific characteristics (e.g., blast disease and lodging resistance, yield, and number of traditional varieties that can be interplanted with hybrid rice, soil and water quality improvement, abundance of aquatic resources) were hypothesized to influence farmers' decisions to adopt the rice varietal mixtures (Table 1).

Years of experience in rice farming is expected to be related to the ability of the farmer to acquire, process, and use information relevant to rice mixtures. A positive relationship is hypothesized between these variables and the probability of adoption of rice mixtures. Household size could affect adoption via household labour supply decisions. Availability of labour positively influences the adoption decision, as it reduces labour constraints faced by the farmer. Education is also hypothesized to positively affect adoption, as the more educated the farmer is, the more receptive he is to new ideas (Oladele and Fawole, 2007). Contact with extension agents is expected to have a positive effect on adoption based upon the innovation-diffusion theory. Such contacts, by exposing farmers to information can be expected to stimulate adoption.

Blast disease reduction is an important attribute desired by farmers. The resistant variety acts as a physical barrier that prevents the spread of the disease from the susceptible glutinous variety. Additionally, due to the height difference between the two varieties, the microclimate in interplanted rice is less conducive to development of the disease than that in monoculture plots. In addition to disease suppression, the use of mixtures has a number of other potential advantages. The taller glutinous rice variety is perceived to be less prone to lodging when interplanted between rows of hybrid rice. Lodging during the milking stage of the rice crop can easily lead to a yield reduction of 500 to 1,000 kg ha^{-1} (Revilla et al., 2003). The perceived higher yield of glutinous rice when interplanted with hybrid rice is expected to be positively related to

Table 1. Definition of farmer-specific and perceived technology-specific variables used in the model, Yunnan Province, China.

Variable	Description
Dependent variable	
MIXAREA	Proportion of farm area under rice varietal mixtures
Independent variables	
A. Farmer-specific	
FARMEXP	Farming experience, years
EDUOP	Farmer's education. Expressed as binary variable: 1, if a farmer finished elementary school, 0, otherwise
HHSIZE	Household size of the farmer, number of people living in the household
EXTCON	Contact with extension workers. Expressed as binary variable: 1, if a farmer had contact with extension worker, 0, otherwise
B. Technology-specific	
BLAST	Blast disease resistance. Expressed as binary variable: 1, if a farmer perceived that rice mixtures would have less blast disease, 0, otherwise
LODGE	Lodging resistance. Expressed as binary variable: 1, if a farmer perceived that rice mixtures would prevent lodging, 0, otherwise
YIELD	Yield advantage. Expressed as binary variable: 1, if a farmer perceived that rice mixtures would give higher yield, 0, otherwise
NVAR	Number of traditional varieties farmers are able to plant as an index of genetic diversity. Expressed as binary variable: 1, if a farmer perceived that rice mixtures would increase genetic diversity, 0, otherwise.
SOILWAT	Soil and water quality. Expressed as binary variable: 1, if a farmer perceived that rice mixtures would result in improved soil and water quality, 0, otherwise
AQUAR	Aquatic resources (e.g., fish, frogs). Expressed as binary variable: 1, if a farmer perceived that rice mixtures would result in increased aquatic resources in the field, 0, otherwise
SEED	Amount of seed required. Expressed as a binary variable: 1, if a farmer perceived that rice mixtures would require more seeds, 0, otherwise
FERT	Amount of fertilizer. Expressed as a binary variable: 1, if a farmer perceived that rice mixtures would require more fertilizer, 0, otherwise
PESTI	Pesticide use. Expressed as a binary variable: 1, if a farmer perceived increase in pesticide use in rice mixtures, 0, otherwise
LABOR	Labour requirement. Expressed as a binary variable: 1, if a farmer perceived that rice mixtures would require more labour, 0, otherwise

adoption and use intensities. Farmers were unable to grow glutinous rice before, as it was susceptible to blast disease. Being able to resume production of traditional varieties with good eating qualities is also hypothesized to positively influence adoption of rice varietal mixtures. With less pesticides being applied, it is expected that there will be significant improvement in the soil and water quality in the field, as well as in abundance of aquatic resources therein. Farmers' awareness of these positive environmental impacts is expected to have a positive influence on adoption decision and use intensity.

It is also hypothesized that adopters of rice mixtures would require much less seeds with the row interplanting method, which will have a positive effect on farmers' adoption decision. With less blast disease in the field, pesticide use is expected to decrease, which will positively influence adoption decision. On the other hand, the higher labour requirements for transplanting twice and harvesting rice varieties separately, is expected to negatively influence farmers' decision to adopt rice interplanting. Fertilizer requirement was also included to examine in what direction farmers will perceive it to influence their decision to adopt the rice mixtures.

Secondary data on number of counties adopting rice mixtures and area under glutinous-hybrid rice interplanting were collected from the plant protection stations and agro-technology offices in different counties of Hong He Prefecture in Yunnan Province.

Tobit model specification

Most adoption studies categorize adoption as dichotomous, and such analyses will not indicate the extent of adoption. In practice, a technology may be partially or fully adopted by the farmers. Schutjer and Van der Veen (1977), in their comprehensive review of adoption studies, concluded that the major technology issues relate to the extent and intensity of use at the individual farm level, rather than to the initial decision to adopt a new practice. The Tobit model (Tobin, 1958) can be used to analyse such decision problems. It has the advantage that its coefficients can be disaggregated into the probability of adoption and the expected use intensity of the practice. The dependent variable for this model is the proportion of the total farm area planted to rice mixtures. This variable has a censored distribution, since it is zero for those not planting mixtures. Tobit models have been widely used in adoption studies (Akinola and Young 1985; Norris and Batie, 1987; Adesina and Zinnah, 1993; Bhandari, 1999; Rajasekharan and Veeraputhran, 2002; Kristjanson et al., 2005). The theoretical framework of the Tobit model can be explained by the threshold concept as:

$$\begin{array}{lll} Y_i = X_i\beta + u_i & if\ i^* = X_i\beta + u_i > T & \text{(Adoption)} \\ Y_i = 0, & if\ i^* = X_i\beta + u_i \leq T & \text{(Non adoption)} \\ & \mathrm{i} = 1,\ldots..,N & \end{array} \quad (1)$$

where,

Y_i = dependent variable for the i^{th} observation (proportion of the area under rice mixtures);

i^* = non-observed latent variable for the i^{th} observation;

T = non-observed threshold level;

X_i = vector of explanatory variables corresponding to the i^{th} observation;

β = vector of unknown parameters associated with the explanatory variables;

u_i = error term assumed to be independently distributed as $N(0, \sigma^2)$;

N = number of observations.

The Tobit model expresses not only the probability that a farmer will adopt rice mixtures, but also the intensity of use of the technology, once adopted. Following a Tobit decomposition framework, as suggested by McDonald and Moffit (1980), the effects of changes in farmer- and/or technology-specific traits on adoption probabilities and use intensities can be obtained.

Let the expected value of the dependent variable MIXAREA be represented by $E(P)$, the expected value of the dependent variable, conditional on the rice farmer being above the threshold limit (i.e., already an adopter and thus now concerned about use intensities) be given as $E(p)$, and the probability of the farmer being above the limit (i.e., the probability of adoption) be represented as $F(z)$, where $z = X_i\beta/\sigma$.

The relationship between these variables can be shown to be:

$$E(P) = F(z) \times E(p) \quad (2)$$

For a given change in the level of farmer- and technology-specific characteristics, the effects on farmer adoption behaviour can be partitioned into two parts by differentiating Equation 2 with respect to the change in the farmer- and technology-specific traits:

$$\delta E(P)/\delta X_i = F(z)\,[\delta E(p)/\delta X_i] + E(p)\,[\delta F(z)/\delta X_i] \quad (3)$$

The relation can be converted into elasticity form by multiplying the equation by $X_i/E(P)$:

$$[\delta E(P)/\delta X_i]\,X_i/E(P) = F(z)\,[\delta E(p)/\delta X_i]\,X_i/E(P) + E(p)\,[\delta F(z)/\delta X_i]\,X_i/E(P) \quad (4)$$

Rearranging Equation 4 by using Equation 2:

$$[\delta E(P)/\delta X_i]\,X_i/E(P) = [\delta E(p)/\delta X_i]\,X_i/E(p) + [\delta F(z)/\delta X_i]\,X_i/F(z)$$

Thus, the total elasticity of a change in the level of any variable consists of two effects:

- the first term is the change in the elasticity of the use intensities of the rice mixtures, for those who are already adopters of rice mixtures, and
- the second term is the change in the elasticity of the probability of being an adopter of rice mixtures.

For the maximum likelihood estimate of limited dependent models, the log likelihood ratio (LR) test can be used to evaluate the significance of all or a subset of coefficients (Greene, 1993). The LR test follows a Chi-square distribution with K degrees of freedom (where K is the number of parameters in the equation minus the constant).

In this study, the estimated empirical model was developed using the farmer-specific attributes and farmer perception variables with respect to the technology-specific characteristics of the rice mixtures technology as explanatory variables. The dependent variable was the proportion of total farm area under rice varietal mixtures.

Results and discussion

Descriptive statistics

In 1998, the rice varietal diversification technology was adopted in only six counties; by 2003, it had expanded to 205 counties (Table 2). The technology spread from 15 ha under rice mixtures in 1997 to 551,334 ha in 2003. This clearly illustrates the rapid rate at which the rice mixture technology for blast suppression was adopted by farmers in Yunnan Province.

Table 3 summarizes the results of the household survey, which was conducted in 2000, when the area under rice mixtures was still rapidly expanding. Three years after the introduction of the rice interplanting technology in Yunnan Province, in the study area more than 50% of the rice area was under mixtures. On average, both, adopters and nonadopters had about 25 years of experience in rice farming, did not finish elementary school and their households consisted of four members. The adopters that participated in the demonstration trials had been more extensively exposed to extension workers than nonadopters. On average, 92% of the adopters had contact with extension workers from the Plant Protection Stations and the Ministry of Agriculture who were responsible for their training on interplanting glutinous rice varieties between four to six rows of hybrid rice, whereas only 3% of the nonadopters had contact with extension workers.

Table 2. Area under rice mixtures and number of counties adopting rice mixtures, 1997–2003, Yunnan Province, China.

Year	Area under rice mixtures (ha)	Number of counties
1997	15	1
1998	812	6
1999	3,342	10
2000	43,000	41
2001	107,400	62
2002	314,368	102
2003	551,334	205

Source: Plant Protection Stations, Yunnan Province.

Table 3. Descriptive statistics of the farmer- and technology-specific variables included in the final model, Yunnan Province, China.

Variable	Adopter (*n*=200)		Nonadopter (*n*=59)	
	Mean	S.E.	Mean	S.E.
Dependent variable				
MIXAREA	0.680	0.12528	0	0
Independent variables				
FARMEXP	25.355	0.76081	24.847	1.38789
EDUOP	0.650	0.33811	0.814	0.51139
HHSIZE	4.000	0.73022	4.170	0.14302
EXTCON	0.920	0.01923	0.034	0.02376
BLAST	0.890	0.02218	0.068	0.03301
LODGE	0.092	0.01867	0.271	0.05838
YIELD	0.895	0.02173	0.152	0.04721
NVAR	0.720	0.03183	0	0

In terms of technology-specific attributes of the technology, farmer adopters in general attached higher perception values to the benefits of rice mixtures such as reduced blast disease (0.89) and yield advantage (0.90). Moreover, adopters believed that rice mixtures would allow them to increase on-farm genetic diversity (0.72) by being able to interplant hybrid rice with other high-quality traditional varieties, susceptible to blast. Surprisingly, nonadopters attributed a higher perception value to the ability of the rice mixtures to prevent lodging of glutinous rice in the interplanting system than adopters.

Factors determining adoption decisions of rice farmers

The Tobit regression model predicting technology adoption was statistically significant (chi-squared = 322.28, df=8; Table 4). The high value of the McFadden R^2 (0.9347) suggests a good fit of the model, indicating that the predicted variables were able to account for 93% of the variability in outcome.

We first run a full model with all the farmer- and perceived technology-characteristics mentioned above and later on dropped some variables that were found not to be significant in explaining adoption decisions. Among the farmer-specific characteristics, only contact with extension agents was found to be significant in explaining farmers' adoption decisions. Perception of blast disease resistance, lodging resistance, higher yield, and increased genetic diversity all significantly and positively influenced adoption decisions. Farmers' contact with extension workers (EXTCON) was highly significant at 1% and positively influenced farmers' decisions to adopt the rice varietal mixtures. Trained technicians in the study area organized, through village officers, small group discussions among farmers. During planting time, the more skilled farmers in the village took the lead to demonstrate to other farmers the

Table 4. Estimated Tobit coefficients for farmer adoption using farmer- and technology-specific variables, Yunnan Province, China.

Explanatory variables	Tobit coefficient	Standard error
Intercept	0.21447***	0.08369
A. Farmer-specific		
FARMEXP	–0.00080	0.00144
EDUOP	–0.01746	0.03311
HHSIZE	0.00472	0.01473
EXTCON	0.33848***	0.05259
B. Technology-specific		
BLAST	0.28029***	0.04383
LODGE	0.11136**	0.05190
YIELD	0.17371***	0.04639
NVAR	0.07467**	0.03548
Log likelihood	–11.260	
LR chi^2 (df=8)	322.28	
McFadden R^2	0.9347***	
Sigma	0.2239	

*** Significant at 1% level

** Significant at 5% level

procedure of interplanting glutinous and hybrid rice, with the agro-technicians as supervisors. Leadership training and facilitating dialogue and communication in village workshops are elements that have been shown to be effective in improving cooperation among all involved in the project. Strengthening local institutions and building confidence in farmer-to-farmer extension appeared to have positive effects on adoption. Contact with extension workers provides farmers with background knowledge and technological options that stimulate discussions and encourage farmers to experiment with options and ideas. This improves communication among the social actors of the development interface by strengthening local institutions.

Household size (HHSIZE) had the expected positive sign, while farming experience (FARMEXP) and education (EDUOP) had negative signs, but were not significant in explaining adoption.

Farmers' perceptions of the technology-specific characteristics of rice mixtures appeared the major factors conditioning adoption behaviour. All four perception variables in the model significantly and positively affected farmers' decisions to adopt the technology. Results of Adesina and Zinnah (1993) and Rajasekharan and Veeraputhran (2002) also support the hypothesis that farmers' perceptions of attributes of agricultural technologies determine observed adoption decisions.

The total effect of changes in the level of statistically significant variables (Table 5) consists of two components: (1) change in the elasticity of the use intensities of rice mixtures, for those who are already adopters; and (2) change in the elasticity of the probability of being an adopter.

With respect to farmer characteristics, the results indicate that contact with extension workers was most influential in their adoption decisions. A 10% increase in farmers' exposure to extension workers is expected to result in a 2.7% increase in adoption and 1.5% increase in use intensities of the rice varietal mixtures resulting in a total elasticity of 4.3%. The rapid adoption of the interplanting technology in Yunnan can thus be partly attributed to the vigorous and systematic programme of communicating information about the technology. The team used communication and extension strategies that were effective in narrowing the knowledge gap between research, extension, and the farm, so that the major barriers to adoption of technology by small-scale farmers diminished significantly (Chambers and Ghildyal, 1985). Scientists played an active role in the research translation process, unlike in the usual scheme of things, in which their role ends when the research report is produced or the publication is accepted (Castillo, 2001). This was a typical case of scientist-policy maker-farmer collaboration, pushing the technology from concept to actual practice. A broad network of researchers, extension personnel, farmers, and government officials from the prefecture down to the village was established.

Table 5. Tobit total elasticity decompositions for changes in the farmer- and technology-specific characteristics perceived by farmers, Yunnan Province, China.

	Elasticity of	
	Adoption probability	Expected use intensity
EXTCON	0.153	0.278
BLAST	0.108	0.236
YIELD	0.054	0.150
LODGE	0.031	0.097
NVAR	0.016	0.067

The vigorous promotional campaigns made many farmers aware of the technology, while the demonstration plots and the experiences of early adopters reinforced farmers' perceptions that the technology was technically feasible and contributed to more complete realization of their objectives.

The most direct benefit from rice varietal diversification was the reduction in blast disease. In monocultures of glutinous rice, yield reductions of 25–40% due to blast are not unusual (Zhu et al., 2001). This is confirmed by the results of the Tobit analysis. Among the farmer perception variables, reduction in blast disease had the highest impact on the probability of adoption and use intensity. Total elasticity is 0.35, i.e. 0.11 for the elasticity of adoption probability and 0.24 for the elasticity of use intensity. This suggests that an expected 10% reduction in blast disease increases the combined probability of adoption and use intensity by 3.5%.

The glutinous monoculture is also susceptible to lodging during strong winds, because of weak stems and tall plants. Interplanting one row of glutinous rice with four to six rows of hybrid rice reduces this susceptibility to lodging, as the shorter hybrid rice has better lodging resistance. A 10% expected prevention of lodging of glutinous varieties results in a 1.3% increase in combined adoption probability and use intensity.

With the interplanting system, farmers are again able to plant many of the high-quality but blast-susceptible traditional rice varieties. Leung et al. (2003) have reported that many traditional varieties that have not been planted for decades are back in production, thus increasing genetic diversity in the rice production landscape. As the interplanted area in Yunnan increased, so did the number of traditional varieties used in mixtures. Farmers now interplant hybrid rice with 26 blast-susceptible high-quality traditional varieties. Adoption probability and use intensity of rice mixtures would increase by 1.3% for each 10% increase in the expected number of high quality traditional varieties that can be interplanted with hybrid rice.

Most of the farmers also perceived that rice varietal diversification resulted in higher yields due to prevention of lodging in glutinous rice and resistance against rice blast. As yields increase, more rice becomes available for home consumption, providing a stronger sense of household food security. Yield advantage in rice mixtures is estimated to increase the total elasticity by 0.20, composed of 0.05 for probability of adoption and 0.15 for expected use intensity.

Conclusions

This chapter has presented a model of adoption and econometric evidence on determinants of rice varietal mixtures adoption and use intensity. The empirical results show that farmers' contact with extension workers and farmers' perception of the inherent characteristics of the technology were significant in influencing farmers' decision to adopt the rice mixtures. This was made possible because farmers who participated in the on-farm demonstration trials had actually seen, felt and acknowledged the benefits of using rice interplanting (blast disease suppression, yield advantage, lodging resistance and increased genetic diversity) and so it was easier for the extension workers to influence their decision to adopt the technology. The vigorous and systematic programme of communicating information about the technology contributed to the rapid adoption and diffusion of the interplanting technology in Yunnan. Moreover, scientists played an active role in the research translation process. This was a typical case of scientist-policy maker-farmer collaboration, pushing the technology from concept to actual practice.

CHAPTER 5

Improvement of technical efficiency in rice farming through interplanting: A stochastic frontier analysis in Yunnan, China

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Abstract

We gathered survey data from a random sample of 200 farmer adopters and 59 nonadopters of rice interplanting in Yunnan Province, China in 2000. The data were used to analyse the effect of interplanting on technical efficiency of rice production and to identify the sources of inefficiency, using a stochastic frontier production function. Results showed that adoption of rice interplanting was the major contributing factor to increased technical efficiency in rice production. Farming experience and access to extension were both significant variables for improving technical efficiency. Whereas the first variable might reflect the skills of a farmer to optimally allocate the resources at his/her disposal, the second variable indicates that farmers who had access to extension agents readily adopted the interplanting technology and as a result performed better. Separate analyses for adopters and nonadopters clearly showed that although rice interplanting was mainly aimed at controlling blast disease, the absence of the disease also increased the responsiveness of output to inputs like labour, seeds and fertilizer. This observation indicates that the improvement of technical efficiency of rice production through interplanting basically results from a positive interaction of various input factors.

Keywords: Inefficiency, interplanting, monoculture, extension agents, farming experience

Introduction

The majority of rural farm households in Yunnan Province in China are poor and rely heavily on agriculture for their livelihood. Revilla et al. (2001; Chapter 3) estimated that annual per capita income of more than 50% of the farm households was below US$187.50, with 39% originating from rice. The World Bank defines as poor those households with a per capita income of less than US$1 per day.

In 1997, a team of scientists from the International Rice Research Institute (IRRI) and Yunnan Agricultural University (YAU) initiated an Asian Development Bank (ADB)-funded project to explore the use of biodiversity through rice interplanting for blast disease management. Since the project area is among the extremely poor areas in China, an increase in productivity and income from the adoption of the rice interplanting would make a direct contribution to poverty alleviation. Thus, although the main objective of the project on rice interplanting was environmental protection by reducing farmers' dependence on harmful agrochemicals, the project was well targeted to make an impact on poverty alleviation. Studying the sources of increased production, examining the extent of inefficiency, and identifying the sources of inefficiency can provide useful insights on how to further improve the conditions of the rice farmers in Yunnan.

Production functions are widely used to analyse efficiency in terms of output for a given level of inputs. In most microeconomic analyses, production functions are estimated under the assumption that producers are rational profit maximizers that operate on their production frontiers. However, Farrell (1957), Aigner et al. (1977), Meeusen and Van den Broeck (1977), and Battese and Coelli (1995) support the view that producers differ in the measured output that they produce from a given bundle of measured input, or, alternatively, in the input requirements to produce a given output. Stochastic frontier analysis (SFA) acknowledges such efficiency differences among farmers. Producers operating on their production frontier are referred to as technically efficient and producers operating below that frontier are called technically inefficient.

Stochastic frontier production functions have been used extensively in the past two decades to analyse technical efficiency. Also in China, several studies have been conducted to analyse the productivity and efficiency in its agricultural production (Travers and Ma, 1994; Fan et al., 1994; Wang et al., 1996a, b; Xu and Jeffrey, 1998; Fan, 1999; Tian and Wan, 2000). The original models of Aigner et al. (1977) and Meeusen and Van den Broeck (1977) have been modified and extended in a number of ways. One development has been to express inefficiency as an explicit function of farm-specific variables. Such a model can be estimated in a two-stage technique, where the stochastic frontier is obtained first and the predicted efficiencies are then regressed upon the farm-specific variables. Battese and Coelli (1995) proposed a simultaneous estimation procedure that has the advantage of providing consistent and efficient estimates.

In this study, we used the SFA specification proposed by Battese and Coelli (1995), to analyse the effect of interplanting on technical efficiency of rice production and to identify the sources of inefficiency. After a first analysis of pooled data, technical efficiencies of adopters and nonadopters of rice interplanting in Yunnan were separately determined.

Methodology

Data collection

Data for this study were obtained from a survey of 260 households in Shiping, Jianshui, Mile Kaiyuan, and Yuxi Counties of Yunnan Province, conducted in July and October 2000. Ten households each from 20 adopter villages and 6 nonadopter villages were randomly selected and the head of the household was personally interviewed, using a semi-structured questionnaire. Adopter villages refer to villages where rice interplanting experiments within farmers' fields had been conducted and farmers had been trained by extension workers. Nonadopter villages were located in areas with much less exposure to extension workers. For the final analysis, one nonadopter was dropped from the sample due to incomplete data. Information on farm household socioeconomic characteristics, output and input use was collected during the survey.

Model specification

Following the specification proposed by Battese and Coelli (1995), this study employs a stochastic frontier production function to measure the technical efficiency of rice production in Yunnan, China. It can be expressed as:

$$Y_i = f(X_i\beta) \exp(V_i - U_i) \qquad i = 1....,N \tag{1}$$

where,

Y_i is production of the ith farm;

$X_i\beta$ is a suitable production function such as the Cobb-Douglas or translog;

X_i is a $(1 \times k)$ vector of inputs of production of the ith farm;

β is a $(k \times 1)$ vector of unknown parameters;

V_i is assumed to be independently and identically distributed (i.i.d.) $N(0,\sigma_v^2)$ random error, independently distributed of the U_i; and

U_i *is* a non-negative random variable, associated with technical inefficiency of production, assumed to be independently distributed, such that U_i is obtained by truncation (at zero) of the normal distribution with mean $z_i\delta$, and variance σ^2.

Equation 1 specifies the stochastic frontier production function in terms of the original production values. The technical inefficiency effect, U_i, in the stochastic frontier model (Equation 1) can be specified as:

$$U_i = z_i\delta + W_i \tag{2}$$

where,

z_i is a $(1 \times m)$ vector of explanatory variables associated with technical inefficiency of production;

δ is an $(m \times 1)$ vector of unknown coefficients.

W_i is a random variable, defined by the truncation of the normal distribution with zero mean and variance σ^2, such that the point of truncation is $-z_i\delta$, i.e., $W_i \geq -z_i\delta$. These assumptions are consistent with U_i being a non-negative truncation of the $N(z_i\delta, \sigma^2)$ distribution.

The method of maximum likelihood is applied for simultaneous estimation of the parameters of the stochastic frontier and the model for the technical inefficiency effects (Battese and Coelli, 1993). The likelihood function is expressed in terms of the variance parameters $\sigma^2 = \sigma^2_v + \sigma^2_u$ and $\gamma = \sigma^2_u/\sigma^2$.

The technical efficiency of production of the i*th* farm is defined as:

$$TE_i = \exp(-U_i) = \exp(-z_i\delta - W_i) \tag{3}$$

The prediction of the technical efficiencies is based on its conditional expectation, given the model assumptions.

Estimation procedure

We used the Cobb-Douglas form of the stochastic frontier production function in this study, estimated as:

$$\mathrm{Ln}Y_i = b_0 + b_1\mathrm{Ln}L_i + b_2\mathrm{Ln}S_i + b_3\mathrm{Ln}F_i + b_4\mathrm{Ln}P_i + b_5D_i + (V_i - U_i) \tag{4}$$

where the technical inefficiency effects were assumed to be defined by:

$$U_i = \delta_0 + \delta_1 EL_i + \delta_2 CE_i + \delta_3 FE_i + \delta_4 HS_i + \delta_5 AD_i + W_i \tag{5}$$

where, Ln denotes the natural logarithm (i.e., logarithm to the base *e*); Y_i represents the aggregate value of glutinous and hybrid rice in Renminbi (RMB) per *mu* (i.e., 1/15 ha); *L* is labour; *S* is the quantity of glutinous and hybrid rice seeds used; *F* is the amount of fertilizer applied; *P* is the amount of pesticides used. All inputs are expressed on per *mu* basis. While *L* is expressed in standard person-days, *S*, *F* and *P* are expressed in value terms (RMB) at 2000 prices (1 US$ = 8.2 RMB). *D* is the dummy variable for adoption of rice interplanting, with a value of 1 if a farmer is an adopter of rice interplanting and 0, otherwise.

Forsund et al. (1980) argued that inefficiency is typically determined by factors associated with farm management practices. Consequently, farmers' education level (*EL*), contact with extension workers (*CE*), farming experience (*FE*), and household size (*HS*) were included in the efficiency function. The first three variables are assumed to be directly related to farmers' management skills, while the latter could impact on his technical efficiency through availability of labour for timely carrying out farming activities.

The stochastic frontier production function, defined by Equation 4, and the technical inefficiency function, defined by Equation 5 were jointly estimated by the maximum likelihood method using FRONTIER 4.1 (Coelli, 1996).

We first estimated a pooled sample model (combined adopters and nonadopters) and found that the dummy variable for adoption of rice interplanting was exerting a strong influence on the production function. We then analysed the data separately for adopters and nonadopters to determine if there was a difference in the output responsiveness to input between the interplanting and monoculture systems.

Results and discussion

Average total value of production of glutinous and hybrid rice varieties was approximately 1,450 RMB mu^{-1} for adopters and 1,000 RMB mu^{-1} for nonadopters (Table 1). On average, yields of glutinous rice on farms with mixed varieties were about 150 kg mu^{-1}, compared to 40 kg mu^{-1} on farms using monocultures. Average yields of hybrid rice were 565 kg mu^{-1}, both in mixtures and in monocultures. Because of the large price difference between glutinous (2.8 RMB kg^{-1}) and hybrid (1.7 RMB kg^{-1}) rice varieties, the difference in average total monetary value of output exceeded that of the average physical yields.

In terms of labour input, adopters of rice interplanting used almost 5 more person-days mu^{-1} than the nonadopters, because they had to transplant and manually harvest the two varieties separately. On average, adopters and nonadopters spent the same on seeds, while adopter farms spent 20% more on fertilizer and 42% less on pesticides.

Adopters and nonadopters both had about 25 years of experience in rice farming, did not finish elementary school and their households consisted of four members. On average, 92% of the adopters had been in contact with agents from the Plant Protection Stations and the Ministry of Agriculture who were responsible for their training on interplanting glutinous rice varieties, compared to only 3% of the nonadopters.

Table 2 shows the maximum likelihood estimates for parameters of the frontier production and inefficiency functions. In the pooled model, the dummy variable for

Table 1. Descriptive statistics of the variables used in the stochastic frontier production and inefficiency models.

Variable Name	Adopter (n=200)				Nonadopter (n=59)			
	Mean	Std dev.	Max.	Min.	Mean	Std dev.	Max.	Min.
Total value of production, RMB[a] mu^{-1}	1449.23	199.60	2124.00	950.00	1007.72	201.23	1404.00	650.00
Labour, person-days mu^{-1}	17.94	9.91	57.03	10.75	13.20	5.31	32.25	6.15
Seeds, RMB mu^{-1}	20.28	8.60	46.50	7.59	20.76	6.47	41.00	10.50
Fertilizer, RMB mu^{-1}	99.88	51.52	431.00	30.00	82.89	47.60	290.00	22.00
Pesticides, RMB mu^{-1}	17.78	13.70	80.00	0	30.66	18.83	110.00	14.50
Education, dummy[b]	0.65	0.48	1	0	0.81	0.39	1	0
Extension, dummy[c]	0.92	0.27	1	0	0.03	0.18	1	0
Farming experience, year	26.36	10.76	53	5	24.85	10.66	50	6
Household size, number	4	1.03	9	2	4	1.10	10	2

[a] Currency in 2000, 1 US$ = 8.2 RMB (Renminbi); 1 *mu* = 1/15 ha.

[b] Education: 1, if elementary graduate, 0, otherwise;

[c] Extension: 1, if contact with extension, 0, otherwise.

Table 2. Maximum likelihood estimates for parameters of the frontier production and inefficiency functions.

Variable	Parameter	Pooled (n=259)		Adopter (n=200)		Nonadopter (n=59)	
		Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Intercept	β_0	0.0768	2.0049^a	0.2630	2.8501^a	0.0030	0.0076
Labour (L)	β_1	0.0081	0.4127	0.1645	1.6816^c	0.0447	0.0712
Seeds (S)	β_2	0.0348	1.8318^c	0.3568	1.9751^b	0.2105	1.8027^c
Fertilizer (F)	β_3	0.0405	2.1335^a	0.4132	2.0969^a	0.0061	0.0536
Pesticides (P)	β_4	–0.0006	–0.1528	–0.3061	–0.7050	–0.1873	–1.9522^c
Dummy for adoption	β_5	0.2653	7.9756^a				
Inefficiency model							
Intercept	δ_0	0.1777	0.9491	0.0631	0.0887	0.2631	0.1562
Education	δ_1	–0.0353	–0.4806	–0.1262	–0.7425	0.0000	0.0000
Extension	δ_2	–0.4193	–1.7860^c	–0.7741	–2.5129^a	–0.1183	–1.0492
Farming experience	δ_3	–0.0080	–1.9620^b	–0.5173	–1.9338^c	–0.3953	–1.8426^c
Household size	δ_4	–0.0459	–0.8883	0.2504	1.0036	0.0097	1.1325
Variance parameters							
Sigma-squared	σ^2	0.7199	2.4878^a	0.2378	3.4962^a	0.8485	1.7297^c
Gamma	γ	0.8352	10.9194^a	0.6838	3.0779^a	0.9588	1.6762^c
Mean technical efficiency		87.12		84.03		76.40	

[a] denotes significance at 1% level,

[b] denotes significance at 5% level and

[c] denotes significance at 10% level.

adoption of rice interplanting was highly significant at 1% and showed the strongest positive effect on gross value of output per mu. This clearly shows that adopting the rice interplanting system led to higher technical efficiency, and as a result, adopters obtained more output. A one percent increase in the number of adopters increased the value of output mu^{-1} by 0.27%. Hence, if farmers want to increase technical efficiency in rice production, shifting to rice interplanting offers ample opportunities. The value of output mu^{-1} increased by 0.04% with a 1% increase in fertilizer dose, and by 0.03% with a 1% increase in seed rate, *ceteris paribus*. The coefficients of labour and pesticides were not significant.

In the inefficiency function, extension and farming experience were statistically significant and had the expected sign. Access to extension services is a conduit for the diffusion of new technology among farmers. Here, it was very clear that access to extension had an impact on farmers' adoption of rice interplanting technology (Chapter 4). Ali and Byerlee's (1991) review of a number of studies on economic efficiency also reports a negative influence of contact with extension services on inefficiency. The coefficient of the education dummy was expected to have a negative sign, assuming that a higher level of education would result in lower inefficiency. Similarly, household size, through its presumed positive correlation with availability of family labour, would reduce labour constraints on the farm and result in more quality labour available for carrying out farming activities in a timely manner, thus making the production process more efficient. Both variables indeed had a negative sign, but neither of the two was statistically significant.

Since rice interplanting had such a dominant effect in the production function of the pooled model, we performed separate regression analyses for adopters and nonadopters, to determine if there was a difference in output responsiveness to inputs between the interplanting and monoculture systems. In the adopter model, all coefficients in the frontier production function, except that for pesticides, were significant and had the expected positive sign. This implies that farmers implementing the rice interplanting system were technically efficient in the use of inputs and, thus, attained a stronger response in terms of output. By planting one row of glutinous between four to six rows of hybrid rice, farmers were able to control blast disease and achieved higher yields (Zhu et al., 2000; Revilla et al., 2001; Leung et al., 2003; Chapters 3 and 6). On top of that, with disease-free and healthier plants, fertilizer inputs became more responsive to output: One percent increase in fertilizer resulted in 0.41% increase in gross value of output mu^{-1}. Similarly, gross value of output increased by 0.36% and 0.16% per one percent increase in seed and labour input, respectively. This shows that in the interplanting system, there is ample scope for increasing the level of output by increasing the level of those inputs. The coefficient for pesticides had a negative sign, but was non-significant. This negative sign indicates that higher pesticide application did not result in increased gross value of output mu^{-1}, as the system of rice interplanting itself controlled blast disease. This implies that farmers were overusing pesticides, possibly as an insurance premium against blast and other pests and diseases.

The coefficients associated with extension and farming experience in the inefficiency function were both negative and statistically significant, implying that both reduced farmer adopters' technical inefficiency. Farmer adopters' access to extension in this model clearly illustrates that those who had been trained and participated in the demonstration trials were making the best out of the interplanting technology and as a result were performing better. Long years of experience in farming also reduced technical inefficiency. As farmers gained more experience, they became better equipped and more knowledgeable in rice farming. Thus, they were more efficient in the use of labour, seeds and fertilizer inputs, which were more responsive to output.

On the other hand, coefficients in the nonadopter model were not highly significant, at best at the 10% level (seeds and pesticides). Obviously, the farmers using the traditional monoculture system of planting glutinous rice used more pesticides, to reduce risks due to blast and other pests and diseases. Farming experience reduced technical inefficiency as evidenced by its negative and statistically significant coefficient.

The results in Table 2 also show that gamma (γ) is significantly different from zero in all the estimated models. In particular the null hypothesis $\gamma = 0$ was rejected in all equations at the 5% significance level. Thus, it can be concluded that technical inefficiencies do exist in Yunnan's rice production: 84, 68 and 96% of the random variation in rice production was explained by inefficiency in the pooled, adopter and nonadopter models, respectively. The observed variations in production efficiency among rice farmers were due mainly to differences in farm practices of sampled rice farmers rather than to random factors. The mean technical efficiency of rice farmers was estimated at 87% in the pooled model, 84% in the adopter model and 76% in the nonadopter model. These values are quite high and comparable to the 87.3% technical efficiency for rice production in Yunnan, reported by Tian and Wan (2000). The results indicate that the average farm produced 87% of the maximum attainable output for given input levels and that an average of 13% was lost due to inefficiency.

In the production ecological approach, a distinction is made between potential, attainable and actual yields (Van Ittersum and Rabbinge, 1997). This concept allows identification of the relative importance of several growth factors and inputs in explaining yield levels and resource-use efficiencies. The potential yield level is determined by the growth-defining factors, i.e., incoming solar radiation, temperature and characteristics of the crop, assuming optimal supply with water and nutrients and complete protection against growth-reducing factors (weeds, pests and diseases).

Water-limited and nutrient-limited yield levels are lower than the potential, due to suboptimal supply of water and/or nutrients, respectively. The actual production level is determined by actual supplies of water and nutrients, and by the degree of yield loss due to growth-reducing factors. Farmers may influence the growth factors and yield levels by various cultivation practices. The gap between actual and attainable yield level can be bridged by yield-protecting measures, while yield-increasing measures narrow the gap between attainable and potential yield. Yield-increasing measures are related to non-substitutable inputs such as water and nutrients, whereas inputs related to yield protection are often substitutable to some extent. Adoption of rice interplanting lowers blast severity and thus helps farmers to reduce the gap between actual and attainable yield. However, the current analysis clearly shows that because of the absence of blast, the new system of rice interplanting creates better circumstances for yield-increasing resources to narrow the gap between attainable and potential yield. While the concept of Van Ittersum and Rabbinge (1997) is useful, we found that in reality, the different yield levels cannot be distinctly categorized as being mutually exclusive. Our results suggest that there is in fact a clear connection between them. In the absence of blast, farmers were able to narrow the gap between the actual and attainable yield and because of that, their output become more responsive to the use of yield-increasing inputs such as fertilizer, thereby simultaneously reducing the gap between potential and attainable yield.

Conclusions

This study used a Cobb-Douglas stochastic frontier model to estimate the technical efficiency of rice production in Yunnan Province, China, and particularly to evaluate the impact of rice interplanting for blast management. The results demonstrate that much can be gained by shifting from monoculture systems of hybrid and glutinous rice to interplanting of hybrid and glutinous rice. The superior performance of the interplanted crop was not only derived from the absence of blast disease, but also from higher productivity of other inputs, such as labour, seeds and fertilizer.

In analysing the sources of inefficiency, two factors were identified. These were farming experience and exposure to extension agents. Farming experience positively impacted on technical efficiency. As a farmer's experience increases, so do his skills in optimally allocating the resources at his/her disposal. Contact with extension agents also had a statistically significant positive influence on technical efficiency. This result reinforces the view that extension access is a necessary catalyst to technology adoption, like in this case, rice interplanting. Therefore, for rice farmers to reduce technical inefficiency, which implies moving to the production frontier, their access to extension services should be improved.

CHAPTER 6

Beyond the rice interplanting system in China[1]

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Abstract

This chapter reviews past and current research on rice disease management with special emphasis on the role of genetic diversity in the evolution and management of rice disease epidemics. Focus is put on the utilization of disease resistance genes and on resolving their contribution towards achieving sustainable crop productivity. With respect to breeding for resistance, attention is given to identification of the right genes and to the development of strategies that optimally deploy these genes in space and time to achieve durability at the cropping systems level. After discussing the rice interplanting experiments conducted in Yunnan, additional case studies, designed to extend the diversification concept to other diseases and cropping systems, are presented. Finally, the future prospects of applying biodiversity to sustain productivity and germplasm conservation are discussed.

Keywords: Genetic diversity, deployment strategies, sustainable disease management, cultivar mixtures, impact, adoption

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Introduction

Host plant resistance is an important tool for rice disease control and has played a key role in sustaining rice productivity especially in tropical Asia. Deploying resistant varieties as a means of disease control is attractive, because it presents no additional cost to farmers and it is environmentally safe (Mew, 1991). Furthermore, resistant varieties can be easily disseminated as seeds leading to wide adoption (Bonman et al., 1992). These are important considerations because for resource-poor rice farmers in developing countries, the options for managing diseases are few. For example, during the 1970s–1980s when epidemics of rice tungro were frequent in the Philippines and Indonesia, farmers expressed more confidence in using resistant varieties than in other control measure. Disease control using chemicals is more common in the temperate or subtropical production environments where farmers apply fungicides for controlling blast (caused by *Pyricularia grisea*) and sheath blight (caused by *Rhizoctonia solani*). Despite regional differences in control measures, planting resistant varieties is considered most effective by rice farmers. Hence, disease resistance breeding has been a major objective in rice improvement programmes conducted at international agricultural research centres, such as the International Rice Research Institute (IRRI) and at the national agricultural research systems (NARS) of developing countries.

There are limitations, however, in using resistant varieties alone to manage rice diseases. Most varieties are resistant only to a few major diseases that are subject of intensive breeding efforts. The rice production environments, particularly in the tropics, are habitats of many rice pathogens causing varying degrees of damage. Even the ‘minor’ diseases collectively could pose a significant threat to production (Mew, 1992). Thus, pathologists and breeders have to deal with yield loss caused by diseases of epidemic and endemic nature. Epidemic loss is dramatic, but less frequent, whereas endemic loss is less obvious but pervasive in each cropping season. Recent surveys indicated that an estimated annual yield loss from 1 to 10% was due to a combination of different diseases (Savary et al., 2000a). Thus, resistance against a few targeted diseases offers only a partial solution to rice disease problems. To those diseases caused by non-specialized pathogens, such as sheath blight and false smut (caused by *Ustilaginoidea virens*), no useful source of resistance has been identified to improve the resistance of rice varieties. To achieve sustainability of rice production in Asia, we need a rice production system built upon effective resistant varieties with broad resilience to a range of diseases and insect pests. Broad-spectrum resistance at the genotypic level and sustainability at the cropping systems level are therefore complementary approaches in managing rice diseases. Although considerable progress has been made over the past decades, much more can be done to integrate these two approaches to achieve results in farmers’ fields.

Modern agricultural development has transformed the diverse, traditional rice production system into a monoculture system that relies only on a few fertilizer-responsive and high-yielding varieties. Farmers' preference to high yield has led to wide adoption of modern rice varieties cultivated in millions of hectares of rice land. Although most modern varieties have built-in resistance against multiple diseases, genetic uniformity inevitably predisposes the system to disease epidemics, and under certain circumstances can lead to serious yield loss caused by diseases and insect pests (Khush and Virk, 2002). Varieties carrying a few resistance genes in a uniform genetic background are vulnerable to rapid adaptation of pathogens and poses uncertainty to farmers. For instance, emergence of new pathogen races caused several blast epidemics in Korea in the 1970s leading to yield losses of 30–40% (Khush, 1989). In the 1980s, other disease outbreaks on a regional scale included epidemics of bacterial blight in northern India and south-east Asia, tungro in south-east Asia, and bacterial blight and blast in Japan (Mew, 1987; Khush, 1989; Teng et al., 1990).

Another impact of the monoculture system is the gradual decline in the diversity of varieties grown by farmers. As modern high-yielding varieties expand to millions of hectares, they replace the traditional varieties. Although useful genes from these traditional varieties are being used in breeding for modern varieties, many unique attributes and gene combinations resulting from years of selection are difficult to reconstitute. To achieve the productivity needed, it is not possible to revert to planting diverse traditional varieties that are poor yielding. However, it is within our capacity to work towards disease management methods that sustain productivity yet maintain adequate diversity and resilience in the production systems.

In the past two decades, IRRI has moved towards increasing genetic diversity of modern rice varieties either through resistance breeding (Khush, 1991; Bonman et al., 1992; Khush and Virk, 2002) and deployment of different resistance genes based on an understanding of the pathogen population structures (Leung et al., 1993, 2002; Leach et al., 2002). This research strategy embraces the principle that genetic diversity is an effective mechanism in reducing disease damage in natural ecosystems, and that it can be used to manage plant diseases to avert crop loss in modern agriculture (Browning, 1974; Wolfe, 1985). These research activities culminated in the initiation of a project entitled "Exploiting biodiversity for sustainable pest management" in 1996 with support from the Asian Development Bank (Revilla et al., 2001; Chapter 3). One of the highlights of this research initiative is the collaboration with Yunnan Agricultural University in applying mixed planting of traditional glutinous rice with modern hybrid rice as a means for blast control. The research suggests a way to manage diseases through the deployment of genetic diversity on a large scale. As a result, farmers' income increases through yield gains and reduced pesticide use. More importantly, it also suggests a way to conserve traditional varieties sustained by economic incentives.

The Yunnan study has stimulated considerable interest in extending the principles of applying genetic diversity for disease control in other crops in developing countries. It is, therefore, timely to discuss the research 'road map' leading to the use of functional diversity to control rice blast, and how the experience gained in Yunnan can be used to improve disease management in the future. We will first review the status of rice disease management and the knowledge and tools available to support various options. We then highlight the experiments conducted in Yunnan and present additional case studies that extend the diversification concept to other diseases and cropping systems. We will conclude by discussing the future prospects of applying biodiversity to sustain productivity and germplasm conservation.

Disease resistance: Key to sustaining productivity

Yield gains due to genetic improvement

Since the first release of the 'miracle' rice variety IR8 in mid-1960, we have witnessed continuous gains in rice productivity up to the present day. This remarkable increase in rice yield has served to achieve food security in Asia (Evenson and Gollin, 2003). At least three factors have made this successful technological change possible: (1) continuous efforts in the development of high yielding semi-dwarf rice varieties by public research institutions and making the seeds freely available to farmers, (2) the dramatic yield increase provided by the improved varieties led to rapid adoption by farmers, and (3) parallel improvement in farming infrastructure to support the cultivation of these modern varieties. Average rice yields in all developing countries rose by 914 kg ha^{-1} from 1961 to 1980 and by 1128 kg ha^{-1} from 1980 to 2000 (Evenson and Gollin, 2003). Nearly 50% of these yield gains were produced by crop genetic improvement (Evenson, 1998; Evenson and Gollin, 2003).

Disease resistance to secure the yield gains

Different genetic components are responsible for the crop productivity gain of more than 2% per year since the 1970s. Among these, host plant resistance against diseases no doubt plays an important role. Table 1 shows the main rice diseases causing varying degrees of economic damage in tropical Asia and the management practices currently used or being explored. The damage caused by these diseases is a function of the prevalence of the pathogen, epidemic potential of the disease, and available control measures. Fortunately, for the most serious diseases with high epidemic potential, control by host plant resistance through genetic means is possible.

Disease resistance contributes to rice yield increase in two ways. It reduces yield

Table 1. Major diseases of rice showing symptoms, the causal organism, prevalence, and management strategies.

Rice disease	Causal organism	Prevalence (affected region and ecosystem)	Management strategy	
			Resistance (R) gene-based	Resource-based
Rice blast	*Pyricularia grisea* (anamorph) *Magnaporthe grisea* (teleomorph)	tropical and temperate regions worldwide in upland and lowland ecosystems	- durable resistance - R gene pyramids - R gene rotation [a] - cultivar mixture - multilines - transgenic resistance [a]	- biological control agents [a] - silicon application [a] - nitrogen and water management - field sanitation - fungicides
Bacterial blight	*Xanthomonas oryzae* pv. *oryzae*	tropical and temperate regions worldwide in lowland ecosystems	- durable resistance - R gene pyramids - cultivar mixture [a] - transgenic resistance [a]	- nitrogen management - field sanitation
Rice tungro	Rice tungro bacilliform and spherical virus	tropical regions in Asia in lowland ecosystems	- host plant resistance - rotation of GLH-resistant varieties - transgenic resistance [a] - cultivar mixture [a]	- synchronous planting - field sanitation
Sheath blight	*Rhizoctonia solani* (anamorph) *Thanatephorus cucumeris* (teleomorph)	tropical and temperate regions worldwide in all ecosystems	- transgenic resistance [a]	- biological control agents - silicon application [a] - fungicides - crop rotation - field sanitation - nitrogen management
Brown spot	*Bipolaris oryzae* (anamorph) *Cochliobolus miyabeanus* (teleomorph)	tropical and temperate regions worldwide in upland and rainfed ecosystems	- host plant resistance [a] - cultivar mixture [a]	- silicon application [a] - fungicides - field sanitation - proper soil nutrition

[a] Mostly at experimental stage, not yet widely practiced.

loss due to diseases and it expands the adaptability of rice varieties to production areas previously limited by high incidence of diseases (Evenson, 1998). For instance, economic impact analysis from India suggests that modern varieties with built-in disease resistance likely contribute 7 to 10% yield gain in rice production (Evenson, 1998). However, there are other diseases in tropical rice production ecosystems that collectively cause chronic yield losses and destabilize annual production. Furthermore, as cultural practices and cropping intensity change over time, some previously ‘minor’ diseases become serious problems. Nearly all resistance breeding efforts are directed against the major diseases with high epidemic potential. It is not known whether the overall improvement in resistance has any effect on the endemic diseases. As the rice production systems evolve, the relative economic damages caused by different diseases need to be updated in order to sustain the yield gain.

Changing production scenarios

To assess the current rice disease problems, Savary et al. (2000a, b) combined field survey data and controlled experiments to determine the production constraints and yield loss under different production scenarios. The group applied non-parametric statistics to quantitatively define rice cropping patterns of various production situations, pest profiles, and crop loss. The results showed that among the many diseases occurring in rice fields, sheath blight and brown spot account for the highest yield loss (6% for sheath blight and 5% for brown spot) across all production situations in south and south-east Asia. Rice blast with a high potential to cause severe epidemics across Asia, is estimated to cause a 0.3–5.0% yield loss, while bacterial blight causes losses of less than 1%.

The results of Savary et al. (2000a, b) seem to contradict the conventional thinking of the relative importance of different rice diseases. For example, brown spot has always been considered a disease resulting from poor soil fertility and not included as a target for disease resistance breeding. However, when viewed in a historical context, the study provides important insights in the changing production scenarios and the shifting problems over time. First, the surveys indicated that the most serious diseases prior to the late 1970s posed a less serious threat to rice production in the late 1990s, even though they can still cause severe epidemics when resistance is insufficient. It supports the notion that the sustained efforts of resistance breeding, started in the 1960s–1970s against blast and bacterial blight, and later against tungro, have paid off. Second, diseases such as sheath blight and brown spot become prominent due to either a lack of effective resistance in the germplasm or a lack of breeding effort. The challenge ahead is to develop broad-spectrum resistance and production systems that suppress a multitude of biotic stresses. To meet such a challenge, research on host plant resistance must evolve not only to respond to the emerging problems, but also to capture advances in science to enable better use of genetic resources in managing diseases.

Finding the right genes

In collaboration with many rice research and breeding institutions, IRRI has taken two approaches to manage rice diseases: (1) incorporating different resistance genes into new varieties, and (2) designing deployment strategies using varieties with different resistance genes. Both approaches rely on the identification of useful genes and a good understanding of the host-pathogen interactions at the organism and population levels. Thus, there is a continual need to understand what constitutes durable resistance to minimize the resurgence of new strains of pathogens. At the same time, we need to understand how diverse genes can be deployed in space or time to achieve durability at the cropping system level.

Using diverse rice gene pool

Disease resistance breeding depends on available genetic variability in the vast collection of germplasm as a source of disease resistance. As of now, many major resistance genes have been identified that condition race-specific resistance against blast (Kiyosawa, 1972; Kiyosawa, 1981; Inukai et al., 1994; Inukai et al., 1996; Imbe et al., 2000; Tabien et al., 2000; Kiyosawa and Ling, 2001; Sallaud et al., 2003), bacterial blight (Mew, 1987; Ogawa et al., 1989; Yoshimura et al., 1998; Zhang et al., 1998; Khush and Angeles, 1999; Leung et al., 2002; Chen et al., 2003; Lee et al., 2003) and more recently, rice tungro (Azzam and Chancellor, 2002). There are over 40 blast resistance genes (*Pi*) and 20 bacterial blight genes (*Xa*) and more are being identified. Of these, relatively few are actually used in commercial varieties on a large scale. Thus, the diversity of resistance genes available for use is much greater than that being used in the field. Clearly, not all resistance genes are equally effective. Also, it is difficult to combine multiple genes based on phenotype alone. The situation is changing as more genes are physically tagged by molecular markers. Different gene combinations can now be created by monitoring the genes with markers in the breeding process (Khush et al., 1999).

Measuring and selecting the right phenotypes

The kinds of genes to be identified very much depend on the phenotypes being selected in a breeding programme. Recognizing the drawback of selecting for absolute immunity (mostly due to race-specific resistance genes with strong effect), there was a shift in emphasis towards partial resistance in the 1980s. It was an important methodological change in the screening of germplasm and breeding lines for a range of diseases including blast, bacterial blight, and tungro in national screening nurseries. This approach in essence ‘relaxes’ the selection to include more diverse genetic mechanisms in the advanced lines in a breeding programme (Bonman et al., 1992).

Creating the genetic stocks to monitor pathogen populations

Although not many resistance genes are actually used in commercial varieties, the diversity of resistance genes has been put to good use in developing differential varieties for pathogen characterization. For example, a large series of near-isogenic lines (NILs) for both bacterial blight resistance genes (Ogawa et al., 1991) and blast resistance genes (Mackill and Bonman, 1992; Inukai et al., 1996; Imbe et al., 2000) have been produced. For tungro virus, several NILs, carrying resistance genes from diverse donors of traditional varieties (e.g., Utri Merah, TKM6) and wild rices (*O. rufipogon*) have been produced (Sebastian et al., 1996; Azzam et al., 2001; Azzam and Chancellor, 2002). These NILs have proven to be excellent experimental materials for differentiating pathogen races, evaluating effectiveness of individual resistance genes (Leung et al., 2002), and molecular cloning of disease resistance genes (Song et al., 1995; Yoshimura et al., 1998; Tsunoda et al., 2000).

Understanding host-pathogen interactions

The development of NILs and molecular markers has provided the essential tools for understanding pathogen diversity and population structures that form the basis of deploying disease-resistant varieties. The NILs carrying individual resistance genes provide an efficient means to detect changes in pathogen avirulence genes corresponding to specific resistance genes. This approach has been widely used in characterizing the bacterial blight (Vera Cruz et al., 2000; Shanti et al., 2001) and blast pathogen populations (Zeigler, 1998; Mekwatanakarn et al., 2000; Thinlay et al., 2000) with the objective of determining the appropriate resistance genes to use and the impact of deployed genes on pathogen evolution. The ecological and population approach to disease resistance breeding was well received by researchers. Since the mid 1980s, a large amount of field and laboratory data have been accumulated on the pathogen populations of *Magnaporthe grisea* (Borromeo et al., 1993; Leung et al., 1993; Chen et al., 1995; Zeigler et al., 1995; Kumar et al., 1999; Mekwatanakarn et al., 2000; Thinlay et al., 2000) *Xanthomonas oryzae* pv. *oryzae* (Leach et al., 1992; Nelson et al., 1994; Adhikari et al., 1995; Ardales et al., 1996; Vera Cruz et al., 1996; George et al., 1997; Shanti et al., 2001) and tungro viruses (Arboleda and Azzam, 2000; Azzam et al., 2000a, b). For *M. grisea*, the pathogen population analysis has defined clonal populations, or lineages, of the pathogen as targets of breeding. A lineage is a group of pathogen genotypes that share a common DNA banding pattern that is inferred to be related by descent from a common ancestor. This led to the formulation of a breeding strategy where major genes are combined to exclude infection by the known pathogen lineages in a location (Zeigler et al., 1994). This ‘lineage-exclusion’ approach is being pursued at Centro Internacional de Agricultura Tropical (CIAT) (Gibbons et al., 2000) and some research groups in Asia (Babujee and Gnanamanickam, 2000).

For bacterial blight, monitoring pathogen adaptation and molecular analysis of avirulence genes have provided useful clues as to which genes are more likely to be effective and durable in a particular environment (Bai et al., 2000; Vera Cruz et al., 2000; Leach et al., 2002). Such advanced understanding of pathogen population genetics and evolution is essential for effective utilization of host resistance genes. As knowledge of pathogen population accumulated, the research also gradually shifted from pathogen population characterization to experimenting with various deployment strategies.

Deployment strategies practised in rice

Sequential release of resistant varieties in time and space

Successful rice breeding programmes regularly release new varieties adapted to various geographical locations. If a variety becomes susceptible to diseases, a new variety with different resistance genes is released to farmers. This replacement method is one way of dealing with multiple diseases and the changing needs of farmers and consumers. In practice, diverse donors with major genes and partial resistance are being utilized in breeding, that on average, 100,000 pedigrees are grown per year and screened for resistance (Khush and Virmani, 1985). This system of screening and breeding has been successful in the tropical irrigated areas. Starting with the release of IR26 in 1973, nearly all released IRRI varieties had multiple resistances to blast, bacterial blight, grassy stunt, and later to tungro (Khush and Virk, 2002). Despite the gradual erosion of major gene resistance, some varieties have shown durable resistance in the tropical irrigated environment. For example, durable resistance to rice blast was observed in IR36 in irrigated tropical areas that is attributed to partial or quantitative resistance (Bonman and Mackill, 1988). For bacterial blight, deployment of a single resistance gene *Xa4* has proven to be effective for a long time. The gene has been incorporated in most of the IRRI varieties (Khush, 1989; Carillo et al., 2002), and varieties with *Xa4* have been resistant to bacterial blight in the Philippines for 20 years, even though compatible races are present (Mew et al., 1992; Vera Cruz et al., 1996). It has been suggested that varieties with the *Xa4* gene also carry multiple minor genes for resistance, such that the apparent durability could be contributed by multiple genes with lesser effects (Koch and Parlevliet, 1991).

Gene rotation based on pathogen race prediction was proposed for rice blast disease management (Crill et al., 1982). In this system, the emergence of new races was predicted to allow replacement of cultivars carrying a different resistance gene before a virulent race could increase to damaging levels. A modified single gene rotation scheme using two resistance genes at the same time was proposed to counter the rice blast epidemic in Korea in 1979–80. In addition to managing blast, a varietal rotation system based on planting different varieties in different seasons or localities was successfully implemented to control rice tungro in Indonesia (Manwan et al., 1985) where rice varieties with different resistance genes against the insect vector green leafhopper were grown in different seasons. In another study, rotating different rice varieties was used as part of an integrated disease management scheme to reduce tungro; however, the success was attributed to synchronous planting schedules rather than varietal rotation (Sama et al., 1991).

Thus, sequential release of varieties over time and space is one form of diversifying varieties or resistance genes used in the field, but this strategy is valid only if the investment in developing a new variety is not out-balanced by the rapid loss of its usefulness. The system would also need to be supported by good race prediction and survey data.

Gene pyramiding

Based on an evolutionary risk assessment model, it has been argued that rice blast and bacterial blight can be managed by gene pyramiding, because it is unlikely that a sequence of multiple virulence will occur in the same clonal lineage of the pathogen (McDonald and Linde, 2002). However, a simulation model of blast evolution by Winterer et al. (1994) showed that gene pyramiding is not an ideal strategy for deployment of blast resistance genes.

Combining multiple resistance genes in breeding lines is difficult by conventional breeding methods due to epistasis (masking effect of one gene over the others). Because many blast and bacterial blight resistance genes have been tagged by molecular markers, gene pyramiding is widely practiced in rice breeding (Nelson, 1996; Khush and Brar, 1998; Huang et al., 1999; Hittalmani et al., 2000; Sing et al., 2001). With marker-based selection, multiple genes can be identified in a single genotype (Nelson, 1996). Thus, DNA marker technology has enabled the use of multiple resistance genes in a single variety, hence increasing the overall diversity of resistance genes used in the field. Using marker-aided selections, several varieties with multiple *Xa* genes have been produced by teams of researchers at Philippine Rice Research

Institute (PhilRice), Philippines, Indonesian Agricultural Biotechnology and Genetic Resources Research Institute (IABGRRI) in Indonesia, and Punjab Agricultural University in India (R. Tabien, M. Bustamam and K. Singh, personal communication). Based on 2–3 years' evaluation in 'hot spot' areas in farmers' fields, these lines showed resistance to bacterial blight under high disease pressure and out-yielded the check. Similarly, major genes for blast resistance (e.g., *Pi1, Pi2, Pi9*) have been accumulated in some elite lines by research teams in Indonesia and India, though the performance of these gene pyramids remains to be tested (M. Bustamam, R. Sridhar, personal communication). Past experience suggests that gene pyramids are most likely to be effective for controlling bacterial blight but less so for blast due to the high level of pathogenic variation exhibited by *M. grisea*. Alternative or complementary strategies are, therefore, needed for effective blast control.

Multilines and cultivar mixtures

A review of the literature indicates that reduction of blast can be achieved in multilines and cultivar mixtures as compared to pure stands (Mundt, 1994; Koizumi, 2001). Based on a simulation model of pathogen evolution, Winterer et al. (1994) argued that varietal mixture is the best deployment strategy for rice blast as compared to gene pyramids and gene rotation. The emergence of complex or 'super' races has not been observed in fields using varietal mixtures or multilines (Chin and Husin, 1982; Chuke and Bonman, 1988; Koizumi, 2001).

Rice varietal mixtures are commonly used in traditional rice culture in Asia and Africa such as in Madagascar and Indonesia (Bonman et al., 1986). In Japan, multilines have been used successfully in commercial production (about 90,000 ha) by varying the composition of individual components according to the prevailing pathogen population (K. Ishizaki, personal communication). Chin and Husin (1982) showed that a mixture containing 66% resistance component lines was adequate to control blast whereas Koizumi (2001) found that 75% resistance in a multiline was required to reduce severity to the level of control achieved by fungicide treatments.

In summary, there have been considerable activities in expanding the genetic basis for resistance in the field. Yet, other than the conventional release of new rice varieties with different resistance genes, most diversification methods have not been adopted or achieved the production scale needed by farmers. The recent interplanting experiments conducted in Yunnan demonstrated that simple methods coupled with strong extension support are critical in disseminating new approaches of disease management.

Varietal diversification: Experiments in Yunnan, China

In order to gain acceptance and adoption of any diversification strategy, positive results have to be demonstrated at the farm level. Such a project was initiated in 1996 to explore the use of biodiversity to achieve sustainable pest management. The work was done using the 'lighthouse concept' in which teams of researchers and extension workers worked together to solve a problem at a target location. Successful demonstration of principles and impact at the 'lighthouse' site helps disseminate the knowledge and technologies to other places. One of the highlights of the project was the application of interplanting varieties to achieve blast control in Yunnan.

Due to the temperate climate and mountainous terrain, blast disease is widespread in Yunnan. In this region, glutinous or sticky rice varieties have high socio-cultural and market value because they are used for confections and other specialty dishes. However, they have low yield potential and are highly susceptible to blast. Before 1998, 98% of the rice fields in the study area were sown with monocultures of hybrid *indica* varieties Shanyou 22 and Shanyou 63. The glutinous varieties were planted in small areas because of their vulnerability to blast. Thus, there are strong incentives for exploring methodologies to address a significant problem of economic interest to local farmers. We summarize below the process and approaches taken that are instructive to future implementation of diversification schemes at large scale.

Early exploratory experiments

In 1997, Yunnan Agricultural University and provincial extension workers approached farmers to implement a genetic diversification experiment in the field. Several diversification options were considered, including seed mixtures of two rice cultivars and planting different varieties in blocks within the same or adjacent fields. Farmers, however, were not receptive to these methods. On the contrary, many farmers had experience in using interplanting of varieties for disease control, but the scale was small with no fixed patterns. The situation presented an opportunity for researchers and extension workers to build upon farmers' experience to develop the proper ratio and spatial arrangement of traditional glutinous rice and modern hybrid rice. The project coordinated seed production and distribution to participating farmers, and supported farmer training on the systematic evaluation and practice of methods of interplanting, and its impact on diseases.

The first experiment was set up in Bao Xiu, Shiping County in small plots (0.07 ha) of participating farms in different villages. Traditional varieties and hybrid rice were planted in alternate strips (3 to 5 rows); however, the result was not satisfactory and disease was severe among the susceptible varieties. At the same time, another varietal diversification experiment was conducted in Zhang Gui Zhai, in Shiping County. Based on farmers' suggestion, one row of glutinous rice was planted for every four or six rows of hybrid rice (Figure 1). Among the various combinations of varieties tested,

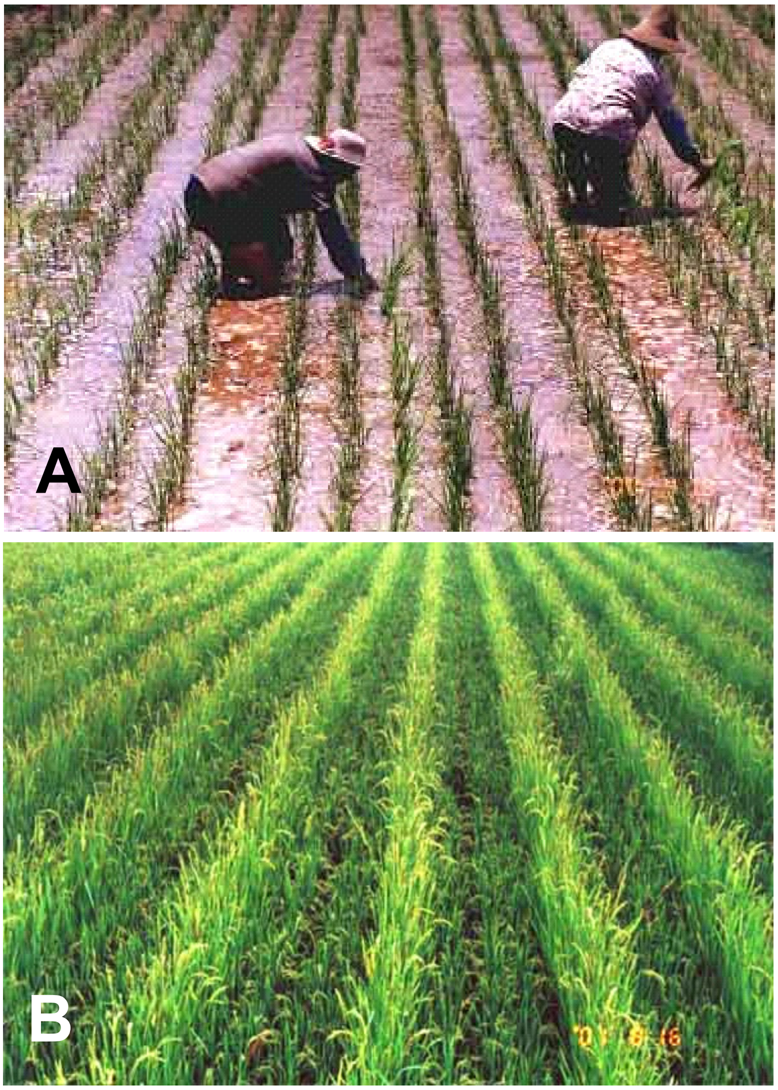

Figure 1. (A) Farmers interplanting glutinous and hybrid rice. (B) Rice field showing the pattern of one row of glutinous rice for every 4–6 rows of hybrid rice.

the mixed planting of glutinous rice variety Huangkenuo or Zinuo with hybrid *indica* rice Shanyou 63 or Shanyou 22 significantly reduced the incidence and severity of rice blast disease and improved yield of the susceptible glutinous rice.

Scaling up

The success in Zhang Gui Zhai led to more demonstration areas and more participation by farmers. In 1998, the team tested this pattern in more fields and in another county, Jianshui. About 812 ha and more than 12,000 farm households were involved in the two counties. The positive results from the previous year prompted the Yunnan Provincial Department of Agriculture (PDA) to support technology extension of mixed planting to other counties in Hong He Prefecture. By 1999, more than 3,000 ha and

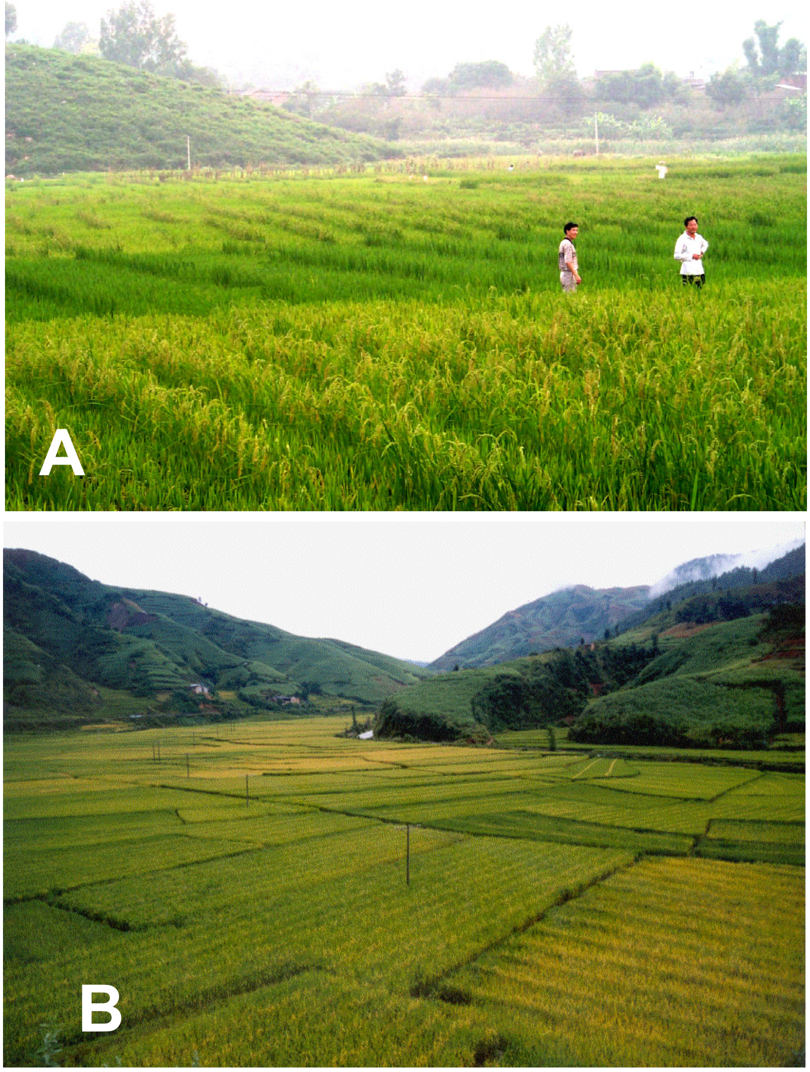

Figure 2. Changing rice landscape in Yunnan, China. (A) Alternating traditional (tall) and hybrid rice (short) are common sights in the countryside of Yunnan. (B) Panoramic view of a village (approximately 1,000 ha) adopting the interplanting method.

45,000 farm households were involved. The PDA and local government units committed additional resources to support training of local farmers from the different villages. Since then, farmers have adopted the basic patterns of interplanting 1 row of tall traditional rice varieties for every 4, 6, 8, and up to 10 rows of hybrid rice, depending on seed supply of the glutinous rice. In less than five years, the interplanting scheme has changed the landscape of the *indica* rice area in Hong He Prefecture (Figure 2).

Results from the first two years confirmed the effectiveness of blast control and profitability of adopting mixed planting of glutinous and hybrid rice. Interplanting of the two varieties significantly reduced blast incidence by 94% on susceptible glutinous rice (Zhu et al., 2001; Zhu et al., 2003). The most successful varietal combination appears to be one row of glutinous rice varieties (either Huangkenuo or Zinuo) to four or six rows of hybrid rice varieties (Shanyou 63 or Shanyou 22). By the end of 2001, about 60% of the farming households in the rice area of Yunnan had adopted interplanting using different pair-wise combinations of hybrids, glutinous rice or other traditional high-quality varieties.

Despite the practical success, the mechanisms involved are not completely understood. It is assumed that the different rice genotypes as well as the undulating canopy in rice fields have created unfavourable environments for blast to develop. The height difference (20 cm) between the two varieties may have produced a micro-climate less conducive to blast infection and pathogen sporulation in the canopy of the susceptible varieties (Zhu et al., 2003). DNA fingerprinting of the fungus also indicated that the pathogen populations were more diverse in fields of interplanting than that in monocultures of either hybrid or glutinous rice (Y. Zhu, Hei Leung, T.W. Mew, and H. Chen, unpublished data). A diverse pathogen population may trigger induced resistance due to incompatible interactions between avirulent pathogen strains and host genotypes. Work is in progress to determine the relative importance of the agronomic and epidemiological factors in reducing disease severity and increasing rice yield as a result of planting two varieties in the same field.

Impact promotes adoption

To understand the basis for the large-scale adoption of the diversification scheme, a second survey of rice farmers was conducted in October 2000 (Revilla et al., 2003). One hundred thirty farm households (100 adopters and 30 nonadopters of the rice interplanting technology) in 13 villages of Yunnan were interviewed. Adopters were asked detailed questions about their farming situation or practices before and after the adoption of mixture planting. The ‘before’ situation refers to the year before 1997, whereas the ‘after’ situation refers to the 1999 rice-cropping season. Similarly, data from the 1999 cropping season were obtained from nonadopters. Results indicate that the rapid adoption is driven by several factors.

Yield gains In general, 25–40% of the yield of monocropped glutinous rice is lost because of blast disease (Zhu et al., 2001, 2003). The traditional varieties also suffer from lodging under windy conditions due to their weak stems and tall stature. On mixture farms, the yield of glutinous rice in 1999 has increased by 0.84 t ha^{-1} (Table 2). Nonadopters obtained less than 0.5 t ha^{-1} of glutinous rice because the crop suffered from lodging at the milking stage. The combined yield of glutinous and hybrid rice was 11.08 t ha^{-1} for adopters versus 9.57 t ha^{-1} for nonadopters. Zhu et al.

Table 2. Mean yield of glutinous and hybrid rice by type of farmer, Yunnan Province, China. Data of adopters refer to either before (1996) or after (1999) adoption.

Rice yield	Adopters (*n*=100)		Nonadopters *(n*=30)
(t ha^{-1})	1996	1999	1999
Glutinous rice	1.30	2.14	0.42
Hybrid rice	8.87	8.94	9.15
Total	10.17	11.08	9.57

Table 3. Cost savings per hectare from reduction in pest pressure, Yunnan Province, China.

Item	Adopters (*n*=100)	Nonadopters (*n*=30)
Number of sprays	0.7	3.4
Cost of pesticides (US$)	15.00	44.20
Labour for pesticide application (d)	2.63	20.76
Imputed cost of labour (US$)	6.05	47.75
Total cost (US$)	21.05	91.95
Financial benefit (US$)	70.90	

(2000) estimated the ecological efficiency of the mixed populations using the concept of land equivalent ratio (LER) and found that an average of 1.18 ha of monoculture cropland would need to be planted to provide the same amounts of hybrid and glutinous rice as were produced in 1 ha of a mixture.

Reduced pesticide use The reduction in blast disease leads to savings from reduced use of fungicides and the labour for spraying. The average number of sprays was 3.4 for the nonadopters compared with 0.7 for the adopters. Because of disease reduction, adopters spent US$15.00 ha^{-1} for pesticides compared with US$44.20 ha^{-1} spent by nonadopters, providing a saving of nearly US$71.00 ha^{-1} (Table 3). There is also a positive effect on the health of farmers and the rice-growing environments.

Increase in farmers' income Because of the increased yields and the high price of glutinous rice, the gross return realized by adopters was higher than that of the nonadopters. By shifting to rice interplanting, adopters in 1999 gained an additional gross income of US$104 ha^{-1} over 1996, when they were still using the traditional system (Table 4). Compared to the nonadopters they even gained an additional US$592 ha^{-1}. Contrary to expectations that rice mixture requires more seeds, adopters spent US$7.87 ha^{-1} less for seed in 1999 than in 1996. This may be due to the more efficient use of seeds by farmers when they follow the straight-row planting of both

Table 4. Costs and returns analysis (in US$) by type of farmer and by year, Yunnan Province, China. Data of adopters refer to either before (1996) or after (1999) adoption.

Item	Adopters (*n*=100)		Nonadopters (*n*=30)
	1996	1999	1999
Gross value of production	2,385.60	2,490.04	1898.10
Price kg^{-1} of			
Glutinous rice	0.47	0.37	0.38
Hybrid rice	0.20	0.19	0.19
Cost of production			
Seeds			
Glutinous rice	2.54	1.90	2.67
Hybrid rice	53.67	46.44	53.30
Fertilizer	182.01	179.51	181.68
Pesticides	19.00	15.00	44.20
Hired labour	469.81	472.15	427.06
Net returns above cash costs	1,658.57	1,775.04	1,189.19

glutinous and hybrid rice. On average, adopters saved US$7.63 ha^{-1} on seed expense compared to nonadopters in 1999.

Although additional labour costs are incurred for transplanting and harvesting, the savings from lower pesticide use and yield gains from glutinous rice more than offset the extra labour costs. Adopters also used more hired labour than before to enable the heads of the household to engage in higher-income-generating off-farm employment. The net returns above cash costs obtained by adopters were US$117 ha^{-1} higher than in 1996, and US$586 ha^{-1} more than those of nonadopters in 1999 (Table 4).

Conservation of traditional varieties The application of genetic diversity by interplanting also allows farmers to bring in many high-quality but disease-susceptible traditional varieties into active production (Revilla et al., 2001; Chapter 3). As the interplanted areas in Yunnan increased, so did the number of traditional varieties used in mixtures (Zhu et al., 2003). Farmers began interplanting hybrid rice with 26 other traditional varieties that have good eating quality, but are susceptible to blast. The number of traditional varieties brought back to production had increased to 105 by 2002. We have quantified the shift in rice varietal diversity in farmers' fields by calculating the diversity index based on the percentages of varieties (treated as genotypic frequencies) planted over 180,000 ha of rice land since 1997. On-farm genotypic diversity has increased from 0 (all hybrid rice) in 1997 to 0.35 in 2002 with

Table 5. Area planted to ten different traditional varieties and index of genetic diversity, Yunnan Province, 1997–2002.

Year	Area under rice mixtures (ha)	Area occupied by trad'l variety (ha)[a]	No. of cultivars	Index of genetic diversity
1997	12.00	2.40	1	0.0000
1998	812.00	162.40	2	0.0018
1999	3,341.80	668.36	3	0.0074
2000	30,867.30	6,173.46	10	0.0667
2001	72,295.00	14,459.00	10	0.1514
2002	179,935.00	35,987.00	10	0.3485

[a] Assumption: Farmers are using the 1:4 ratio of hybrid and traditional rice, hence only 20% of the area is estimated to be planted to traditional varieties. By 2002, at least 10 traditional varieties were in active production in the 180,000 ha area surveyed.

10 different traditional varieties occupying substantial areas (Table 5). Such baseline data will allow us to determine the relationships among genetic diversity, yield stability, and farm income in the long term.

In summary, the technology of interplanting spread from a mere 12 ha in an initial experiment involving two counties in 1997 to 812 ha in 1998 and 43,000 ha in 2000. By the end of 2001, about 70% of the farm households in the rice area of Yunnan had adopted mixed planting of rice varieties and the area under mixtures had expanded to 107,400 ha in 61 counties. In 2002, rice interplanting covered an area of 230,000 ha in 101 counties of Yunnan. Ten additional provinces in China have evaluated the diversification scheme and are prepared for large-scale implementation. Such rapid adoption can be attributed to the simplicity of the method and the systematic extension effort involving county and village officials, researchers, and extension workers (Castillo, 2001). The extension network ensures not only that farmers are trained but also that seeds are available at planting time.

Beyond the interplanting experiments

The success achieved in Yunnan has generated considerable interest in varietal diversification and at the same time raised a number of questions. Can a similar approach of interplanting be extended to other crops? Will it work in different rice production environments and in different countries? It should be emphasized that the interplanting method is one form of diversification. While interplanting may be applicable to some other cropping systems, it is by no means a universal method to be practiced in all situations. Rather, it is the diversification concept that is of central interest in achieving sustainable crop productivity. The important lesson learned from the Yunnan experiments is that diversification can be effective and agronomically feasible, provided that the implementation strategies are compatible with farmer cultural practices and that the results are economically attractive. In the long term, the strategy helps preserve traditional varieties with useful traits such as grain quality and adaptability. To generalize the diversification strategy, it is important to demonstrate its effectiveness in additional locations and/or cropping systems. We are currently evaluating various diversification approaches in different settings, with the hope that each case study can reveal new insights on how diversity can benefit crop production.

Rice blast in the uplands in Indonesia

Rice blast is considered the most limiting constraint in upland rice production in Indonesia (Suwarno and Soenarjo, 2001). Unlike the situation in Yunnan, where the traditional varieties are mostly susceptible, the traditional upland varieties in Indonesia have good to moderate levels of blast resistance. In contrast, the modern varieties released to farmers succumb to blast within 2–3 years (A. Hasanuddin, M. Syam, E. Soenarjo, Suwarno, Mukelar, personal communication). Farmers would like to plant modern varieties that give higher yield to raise their income, yet retain the traditional varieties for consumption and as insurance against blast epidemics. If interplanting can protect the modern varieties against blast, it would help to increase the productivity per unit area and sustain the use of traditional varieties.

Pilot field experiments are being conducted using a blast-resistant traditional variety Sirendah and a susceptible modern variety Cirata in disease hotspots in Lampung, Indonesia, to evaluate various interplanting schemes. Preliminary observations suggest that leaf blast severity at the maximum tillering stage is less in the interplanted plots (3 and 4 rows of Cirata and Sirendah, respectively) than in the pure stand. However, there is no significant reduction in neck blast (N. Castilla, W. Sabe Arjasa, A. Mukelar, pers. communication). It appears that while interplanting may have a disease-reducing effect, a threshold level of resistance in the ‘susceptible’ varieties is needed to benefit from the interplanting method. Work is in progress to introduce improved varieties with a higher level of blast resistance in the interplanting scheme.

Rice tungro viruses in the Philippines

Only in recent years has genetic resistance against tungro been identified and incorporated into advanced breeding lines (Sebastian et al., 1996; Azzam and Chancellor, 2002). Several sources of tungro virus resistance from traditional varieties and wild species have been incorporated into elite genetic background. Furthermore, near-isogenic lines with and without resistance genes have been produced, making it possible to test mixture varieties. Experiments are being conducted in Iloilo in the Philippines, where tungro is common and often reaches epidemic proportions. In this region, farmers prefer growing IR64, which has good eating and milling qualities. Thus, it is advantageous to retain as much IR64-like varieties as possible in the field, even though IR64 is highly susceptible to tungro.

The mixture deployed for tungro management in Iloilo involves mixing seeds in a 1:1 ratio of two rice varieties with similar plant types, eating quality, and maturity, but differential resistance to the tungro virus. Results from two crop seasons showed a 50% reduction in tungro incidence in the mixture relative to the pure stand. Farmers were receptive to the seed mixture and harvested the crop as a mixture and saved the seeds for the next planting (R. Cabunagan and I.R. Choi, pers. comm.). The positive result has prompted other farmers in the region to test seed mixtures in their own fields. However, more performance data on the seed mixtures under high disease pressure are needed to determine if tungro resistance and yield gain is stable under stress.

Wheat stripe rust and broad bean fly and foliar disease in Yunnan

To extend the diversification concept to other crops, experiments have been conducted by Yunnan Agricultural University (YAU) to evaluate the interplanting method in wheat and broad bean. As part of a rice-wheat cropping system, wheat and broad bean are planted during winter on more than 250,000 ha in Yunnan. Wheat stripe rust caused by *Puccinia striiformis* is a major disease problem, causing yield losses as high as 15–20%. Broad bean is an important cash crop planted in the same season as wheat, but bean yield is often low because of a serious foliar disease caused by *Botrytis fabae*, and root and stem damage caused by bean fly maggots (*Ophiomyia phaseoli*). Researchers at YAU introduced intercropping by planting wheat in blocks of 1 m × 20 m and planting two rows of broad bean between the blocks. Results from five locations in Yunnan showed that the intercropping design reduced the incidence of wheat rust by 24%. Damage caused by bean fly maggots decreased by 19%. The intercrop maintained the same yield of wheat (4,791 kg ha^{-1}) as in monoculture (4,757 kg ha^{-1}), but gained an extra harvest of 656.6 kg ha^{-1} of broad bean.

Understanding and incorporating diverse genetic mechanisms

The above case studies demonstrate a diversity of ‘diversification schemes’. Our experience so far suggests that while diversification is generally sound, implementation of the specific methods has to be tailored to the practices of different cropping systems and characteristics unique to different pathosystems. For instance, in interplanted fields where blast was effectively controlled, we observed frequent occurrence of sheath blight and false smut. Thus, interplanting does not suppress all diseases. Clearly, the genetic composition of the varieties and epidemiological characteristics of the disease are important factors in determining the kind of diversification strategies most appropriate for certain production environments. The experiment in Indonesia will be informative, as it is designed to test whether resistant traditional varieties can be used to ‘protect’ modern high-yielding varieties through interplanting. More case studies, such as this, are needed to develop diversification methods suitable for different cropping systems.

Good germplasm with respect to functionality is the foundation of any of the diversification strategies. ‘Good germplasm’ does not necessarily mean improved modern varieties. Rather, germplasm with different attributes in quality, adaptability and/or tolerance to different pests and diseases can be used in different combinations to achieve agronomic complementarity. In Yunnan, the original pattern of interplanting traditional and hybrid varieties has been modified to include planting two traditional varieties with different agronomic attributes and eating qualities. Traditional varieties, as the result of years of natural and on-farm selection, are full of valuable traits. The challenge is learning how to determine or predict the performance of these traditional varieties such that they can be used by virtue of their agronomic complementarities with other, improved, germplasm.

Application of biodiversity, therefore, can be enhanced through a better understanding of the genetic diversity of traditional and improved germplasm. With recent advances in genomics, new opportunities exist to associate genes with phenotypes at a genome-wide scale. In the context of applying biodiversity for disease management, we envision at least two applications in the near future. First, germplasm with diverse genetic resistance mechanisms can be produced in a more efficient way. Genes can be selected to confer different mechanisms of resistance. Liu et al. (2004) recently reported the application of candidate defence genes to develop blast–resistant breeding lines with resistance to diverse pathogen populations. The ability to precisely select for specific genotypes will yield valuable germplasm as ingredients for any diversification programme. Second, we foresee the possibility of functional prediction of agronomic complementation by examining a large number of genes in the germplasm pool. In this way, traditional varieties can be pre-selected for use in different diversification schemes. To test this hypothesis, we are applying molecular markers to determine the genetic distance between modern and traditional varieties in Yunnan and test if there is any positive correlation between genetic distance and field performance observed in interplanting experiments.

Future perspectives

We have reviewed the evolving research strategy that emphasizes the use of genetic diversity as a means for managing diseases in a sustainable manner. By examining the research 'road map', we gain clarity in the emerging needs and also new possibilities in solving rice pathology problems. The survey of Savary and colleagues (Savary et al., 2000a, b) indicates the importance of maintaining genetic resistance to the major diseases of high epidemic potential. Furthermore, the relative low incidence of diseases in the large area of unfavourable environments is largely due to low productivity. As we seek to improve productivity in these areas, disease problems will become more prominent. Thus, there should be no complacency in developing better germplasm and varieties with broad-spectrum disease resistance. Yet, for some areas, increased production alone does not necessarily bring about high income for the farming community because of depressed rice prices. Farmers prefer growing high-value agricultural products – including high quality and specialty rice that commands a higher price in the market. Thus, a production system that allows high productivity per unit land area through better crop protection and coexistence of traditional and modern varieties will be well accepted by farmers.

Because of the evolving pathogens and changing cropping systems, maintaining plant health requires anticipatory and proactive strategies. Genetic diversity is the 'currency' to manage the 'arms race' between the pathogen and host genotypes introduced by breeding (Figure 4). At the genotypic level, broad-spectrum resistance for major and minor diseases, using different genetic mechanisms is important. With the rice genome sequence available (Goff et al., 2002; Yu et al., 2002), we have the

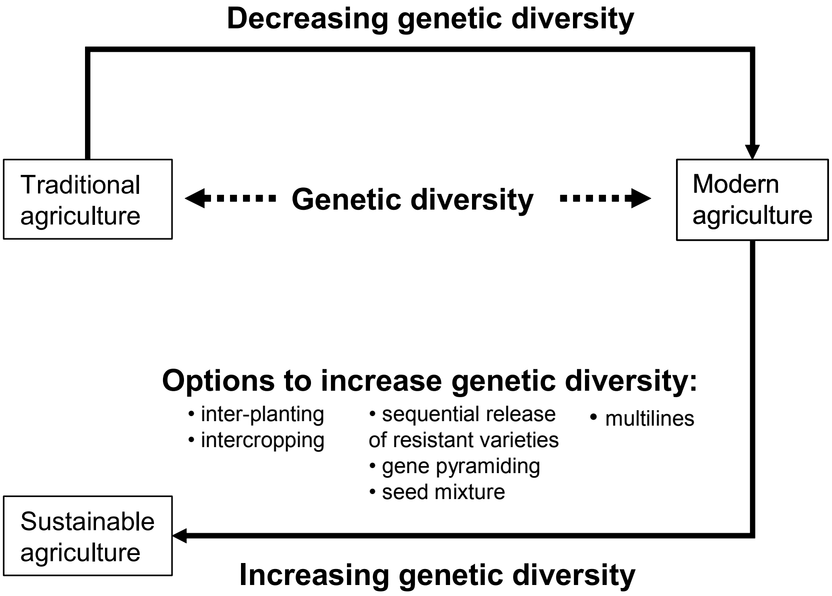

Figure 4. Roles of genetic diversity in modern agriculture and options to increase genetic diversity in achieving sustainability.

capacity to identify a large pool of resistance genes and defence-response genes that encode multiple mechanisms of resistance. Knowing how these genes function will undoubtedly improve our ability to use them effectively. At the cropping system level, we will need to go beyond the deployment of resistance genes in a variety but consider using a large suite of agronomic traits that together provide enhanced resilience to a wide range of stresses.

Traditional varieties are often only seen as a ‘donor’ of useful genes and little attention has been given to their utility in a high productivity system. Our experience in Yunnan indicates that capitalizing on this valuable resource does not necessarily mean ‘converting’ these traditional varieties into modern genotypes by breeding. In many situations, traditional varieties are highly valued for a variety of reasons such as aesthetic, eating qualities and ceremonial needs. Farmers are interested in growing them to meet such needs and to receive higher returns in the market place. Thus, the ability to grow these varieties without altering certain traits, should be considered as a complementary strategy in modern rice production. The Yunnan experiment represents a successful case where traditional varieties can be co-cultivated in a highly productive system. Extension of such a system, or a variation of it, can provide a strong incentive for the conservation of traditional varieties by local communities, contributing to the long-term preservation of genetic resources.

Since the Green Revolution, a major objective of rice disease control has been preventing yield loss. Although this objective has not changed, there is the added impetus that crop protection should be conducted in the context of improving the livelihood of the rural poor and preserving limited natural resources. We have shown case studies where management of diseases through the use of genetic diversity can contribute to the development of broad-spectrum resistance, generation of income, and conservation of genetic resources. The scientific bases for implementing these approaches are much stronger now than what we had decades ago. The future challenge as well as excitement lies in merging new science with on-farm practice to bring about benefits to the local community.

CHAPTER 7

General discussion

The re-shaping of the rice production landscape in Yunnan province in China in the last decade is witness to the dramatic changes in rice production systems that have taken place in this area. In this chapter, we reflect on the reasons underlying these changes and their impact on farm households in the region. The chapter begins with an introduction into the importance of exploiting biodiversity as an approach to managing diseases. Some examples are cited where the use of genetic diversity has been shown to be effective in controlling diseases. Difficulties associated with implementation of diversification strategies are discussed. We then slide into the Yunnan experience with the rice varietal mixtures and discuss the advantages and disadvantages of using the rice interplanting system. A discussion follows on our understanding of the reasons for the rapid and large-scale uptake of the rice interplanting technology in Yunnan. We conclude the chapter by reflecting on the lessons learnt and on the possibilities to replicate Yunnan's rice interplanting success story.

Exploiting diversity to manage diseases

The continuously rising demand for food requires increased agricultural production, either by expanding farmland or intensifying its cultivation (Khush, 2005; Hossain, 2007). Both approaches have attracted criticism for their perceived conflict with the conservation of natural resources and biological diversity (Roetter and Van Keulen, 2007). This is a particularly contentious issue in modern crop-production systems that are based on cultivation of high-yielding input-responsive varieties. Most modern varieties (MVs) perform well relative to traditional varieties, even under unfavourable production conditions, but they express their full yield potential only under favourable conditions with optimum management. Because of their responsiveness to external inputs, MVs became an important catalyst for the adoption of chemical fertilizers and irrigation (Morris and Byerlee, 1998). The introduction and spread of MVs also precipitated a sharp increase in the use of pesticides, especially in rice. Simplification of the ecosystem by using one-sided crop rotations, monocultures, and crop plants of uniform genotype, and the elimination of weeds with herbicides results in a strong selection for adapted pests, pathogens, and weeds, leading to frequent resistance break-down and severe pest outbreaks and weed infestations. The use of a few high-yielding varieties has also caused diverse traditional varieties with high adaptability to hetero geneous environments to be irreversibly displaced and lost (Smale, 1998; Hogg, 1999).

Attempted solutions to the problems associated with modern agro-ecosystems, such as the overuse of fertilizers and pesticides, are usually expensive and often lead to new problems (Wolfe, 2000). These environmental concerns have stimulated research into solving problems associated with biotic stress factors with reduced use or complete elimination of biocides. This has resulted in the development of so-called integrated pest management (IPM) strategies, in which biological control, host plant resistance and appropriate farming practices are combined, leading to minimal use of pesticides. IPM appears an attractive option for the future, as it guarantees yields, reduces costs, is environmentally friendly and contributes to the sustainability of agriculture (Waibel, 1986; Williamson et al., 2008).

An alternative direction has been to utilize and exploit genetic diversity. Apart from resistance breeding, this approach includes the use of different temporal and spatial arrangements to combine two or more crop species or varieties.

Research has been initiated to elucidate the mechanisms that are responsible for the disease-suppressing effects of such diverse systems. Several studies (Vandermeer, 1989; Andow, 1991; Finckh and Wolfe, 2006) have indicated that intercropping can be beneficial for insect pest control. Some hypotheses for the mechanisms of interactions such as the natural enemies and resource concentration hypotheses have been proposed (Letourneau, 1977; Altieri and Letourneau, 1982; Andow, 1991).

The use of weed-competitive cultivars, intercropping and rotational cover cropping all contribute significantly to the management of weed populations (Bastiaans et al., 2007). Baumann et al. (2001) found that intercropping leek (*Allium porrum* L.) with celery (*Apium graveolens* L.) reduced growth and yield potential of weeds in leek production, while maintaining productivity. Kruidhof et al. (2008) observed that inclusion of cover crops in crop rotations in late summer and autumn prevented growth and development of weeds through competition. Incorporation of the cover crop residues in spring further suppressed and retarded weed development and growth, due to allelopathic effects.

For diseases, the use of cereal variety and species mixtures has been proposed as a powerful tool in reducing the risk of resistance breakdown and still make use of defeated genes (Finckh et al., 2000b). Barrier and frequency effects, and induced resistance are the most important mechanisms reducing disease pressure in variety and species mixtures.

Implementation of more diverse systems

Following assessment of the beneficial effects of diverse systems in reducing the negative impact of diseases and pests, practical difficulties had to be solved to implement these diverse systems.

Diversification is complex to deal with if more than one crop/variety is grown on the same field, as it may need specially adapted machinery. Difficulties in mechanization restricted the applicability of intercropping to allotment gardens and labour-intensive farming systems in the tropics (Baumann et al., 2001). Intercropping also entails higher labour requirements. In Chapter 3, we have shown that the technology of rice interplanting is not costless. Farmers incurred substantial additional costs, particularly in two farm operations. One is for transplanting labour, because the rice mixture requires transplanting twice. Another is for harvesting, because farmers have to manually harvest the glutinous and hybrid rice separately, as they have different qualities and prices in the market. A related aspect is the consumer and producer demands for high standards with respect to uniformity and quality of produce from mixed systems such as varietal mixtures of cereals. In some countries, there is resistance in the food processing industry to such products. As a consequence, the uptake of varietal mixtures has been limited by the uncertainty of farmers about their ability to sell the grain to industrial end-users (Finckh et al., 2000a).

The successful adoption of the rice interplanting system

Given the constraints indicated, it is surprising that the rice interplanting system was taken up so rapidly and at such a large scale in Yunnan Province in China. The research presented in this thesis has provided clues on why the adoption was so successful.

1. The system provides effective disease suppression

Whereas some other systems provide useful contributions to disease suppression, the interplanting system really makes a difference. By planting one row of glutinous rice between four to six rows of hybrid rice, farmers were able to fully control blast disease (Zhu et al., 2000; Wolfe, 2000). This spectacular reduction in blast was constant over the whole province where rice interplanting has been adopted by farmers. With the taller glutinous rice interplanted between rows of the shorter hybrid rice, the system provides effective suppression of blast disease. The resistant hybrid rice acts as a physical barrier that prevents the spread of the disease from the susceptible glutinous rice. This is like a fire that started from a susceptible variety. Here the hybrid rice variety acts as a firewall preventing the spread of the fire. In addition, because of the height difference between the two varieties, the microclimate in mixtures is less conducive to spread of the disease than in monoculture plots. The rice interplanting system thus allowed cultivation of glutinous rice again, that had all but disappeared because of blast disease.

2. The system provides additional advantages

In addition to blast disease suppression, interplanting glutinous rice with the hybrid variety prevents lodging. As described in Chapter 2, in the current study, prevention of lodging of the tall glutinous rice by the lodging-resistant hybrid rice was identified as an important additional advantage of rice varietal mixtures. Moreover, in Chapter 5, we have shown that farmers implementing the rice interplanting system were technically more efficient in the use of inputs and, thus, attained a stronger response in terms of output. By planting one row of glutinous between four to six rows of hybrid rice, farmers were able to control blast disease and attain higher yields. With reduced disease pressure and healthier plants, the system became more responsive to fertilizer and labour inputs. .

3. An effective extension program was implemented.

Science did not just produce an answer, but science was also involved in developing a participatory extension program (Chapters 3 and 4). Demonstration trials were installed in villages, and county and village officials, researchers, and extension workers from plant protection stations and the Ministry of Agriculture intensively interacted with farmers. The analysis in Chapter 4 shows that farmers who came in contact with extension agents easily grasped the advantages of the system and, as a consequence, adopted the new technology. Blast disease suppression, yield advantage, lodging resistance and increased genetic diversity were perceived by adopters as the most important advantages. Tobit analysis showed that farmers' recognition of these advantages played a major role in their decision to adopt the system. Implicitly, it also demonstrated that the extension program was very successful in carrying the message to the farmers.

4. The special place of glutinous rice

Next to the higher price of glutinous rice, its special position in the culture of the population of Yunnan probably also played a very important role. An ancient Chinese proverb says “Without rice, even the cleverest housewife cannot cook.” In a poignant manner, this proverb illustrates an important point – rice serves essential functions to the people of China: of course in first instance as the pillar of food security, but for the sticky rice variety also for special functions. As described in this thesis, there is a high demand for glutinous rice in Yunnan Province. Sticky rice confections are served during Chinese festivals to symbolize closeness among members of the Chinese family. Practically every festival or family occasion is celebrated by serving specialty dishes made from glutinous rice.

Can this success be replicated?

The rice interplanting project in Yunnan was a unique experience, where scientists, extension workers, farmers, policy makers and funding agencies have worked together towards a common goal (Castillo, 2001), which has resulted in rapid and large-scale adoption of a new technology. The lessons learnt from this system and the knowledge gained will be relevant for other areas and agro-ecosystems. Chapter 6 already deals with the more technical aspects of utilizing diversity for suppression of other rice diseases. But the question whether technology adoption will be equally successful remains. Can this success be easily replicated?

This question raises another question. Can we control all relevant factors and aspects to repeat the success story of rice interplanting in Yunnan? A combination of controllable factors and to some extent rather accidental circumstances and conditions is apparently responsible for the enormous success of the rice interplanting system in China.

This thesis has clearly illustrated that some factors were under the control of scientists (how effective is the system) and extension (how good is the message brought to the farmers). Although the simple scheme of the interplanting system is based on ecological principles, *biodiversity for sustainable pest management*, its promotion and translation into farmers' fields is *mixture planting* (Castillo, 2001), which turned out to be a very effective system. Although some disadvantages and costs are involved, the benefits derived from the system far outweigh these negative aspects. In this study, it was shown that glutinous rice could be grown again, with minimum or even without use of expensive fungicides. With 20% less land allocated to hybrid rice, yields of hybrid rice were hardly affected (Chapters 2 and 3). It was estimated that, on average, 1.18 hectares of monoculture cropland would be needed to produce the same amounts of hybrid and glutinous rice produced on one hectare of a mixture (Zhu et al., 2000).

However, some factors are beyond the control of scientists and extension agents, such as the special position that glutinous rice occupies in Chinese culture. Coming back to the question of whether we can have a repeat of the success story in Yunnan. This work suggests that it is unlikely to be repeated at a similar scale. The special combination of technical and social factors in the region provided a recipe for success, and makes the Yunnan experience unique. It was a classic case of scientists–extension agents–policy makers–farmers collaboration in pushing the technology from concept to actual practice. Moreover, as glutinous rice is in high demand and has high socio-cultural value in addition to the financial value, farmers readily perceived the advantages of the technology which led to rapid adoption at large-scale.

Preservation of genetic diversity

An additional and unintended advantage of the large success of the interplanting system is its contribution to preservation of genetic diversity. As of 2002, over 26 high-quality but blast-susceptible traditional varieties are being grown again in combination with hybrid rice. This advantage was also recognized by farmers, which increased the adoption probability and use intensity of rice mixtures in Yunnan (Chapter 4).

The way ahead

The rice interplanting system in Yunnan has shown that it is possible to combine modern and traditional rice varieties to control blast disease, achieve acceptable crop yields and provide good-quality food and income for the rural population. By re-introducing traditional varieties into a productive, but sufficiently diverse ecosystem, we can harmonize *in situ* conservation with intensive production systems. It has also shown that farmers' early participation in the project is a crucial factor in showing the impact of using the technology and subsequently in its adoption. As Castillo (2001) puts it "impact must be seen, felt, and acknowledged *by farmers*, *not just by scientists*. Even when positive gains are computed by economists, but farmers do not experience those gains, we probably have not made a noticeable and felt difference."

The Yunnan experience has also demonstrated that the best way to push a technology from concept to actual practice is to strengthen the links among research, extension, policy makers and farmer communities.

While we have shown the benefits of using rice interplanting and documented its large-scale adoption, a number of issues remain unanswered.

- Despite the advantages of rice interplanting, how come there are still nonadopters? How can nonadopters be convinced to use rice interplanting?
- Would farmer's initial gain in profits not be dampened when there is more supply of glutinous rice available in the market?
- Can we expect the same impact and extent of adoption in other countries, such as in the Philippines and Indonesia where a similar approach of rice mixtures is being attempted?

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Summary

The Green Revolution that started in the mid-1960s has resulted in a dramatic increase in global food production, as a result of widespread adoption of new technologies that combined new high-yielding varieties with high inputs of yield-increasing and yield-protecting inputs, stimulated by the implementation of enabling policies. However, one of the consequences of this development has been an equally dramatic decline in the diversity of plant species and varieties that we depend on for our food supply, so that currently, the human population is fed to a large extent from a very limited number of varieties of only 15 plant species. This genetic uniformity in current agro-ecosystems has been widely recognized as a crucial factor in stimulating the development of diseases and pests and the subsequent development of epidemics. To prevent outbreaks of such destructive epidemics in extensive monocultures, regular, often intensive, use of pesticides became a standard component of crop management. The negative effects of over- or injudicious use of pesticides on human health and environment then increasingly became a serious societal concern. In response to these concerns, research was initiated into the development of alternative pest management systems. One approach has been the purposeful introduction of biodiversity in cropping systems as a means of controlling disease and pest outbreaks.

The experience on rice blast in Yunnan Province, China, is one of the most successful and widely publicized examples of genetic diversification for disease suppression in practice. The wet, cool climate of the province is highly favourable for the development of rice blast epidemics. Throughout its history, therefore, blast outbreaks have caused serious yield losses. Following successful resistance breeding, rice blast no longer created serious problems in the hybrid *indica* rice varieties, but remained a problem in cultivation of the preferred special-purpose glutinous varieties. Before 1998, farmers had to spray fungicides three to eight times per cropping season in order to successfully grow a crop of glutinous or sticky rice. To reduce farmers' dependence on these harmful agrochemicals, a team of scientists from the International Rice Research Institute (IRRI) and Yunnan Agricultural University (YAU) initiated a project in Yunnan Province with the objective to explore the possibilities of using biodiversity as a means to control blast outbreaks, and through the associated increase in farm productivity and income, contribute to poverty alleviation.

The technology developed in the project, of interplanting one row of high-value, but blast-susceptible glutinous rice, with four to six rows of blast-resistant hybrid *indica* rice varieties, was adopted rapidly and at large scale by the farmers in Yunnan: from a mere 15 ha in 1997, adoption increased to over 550,000 ha in 2003. In order to learn

from this experience, we have to understand the process by which the technology of rice interplanting was introduced and scaled up. What was the impact of adopting rice interplanting on farmers' pest management, yield and income? What were the key elements in the process of technology diffusion? What were the major factors that conditioned farmers' decision to adopt the rice varietal mixtures?

In this study, we analysed the effects of genetic diversity on blast management and determined the socio-economics, i.e., productivity and farm income, of using genetic diversity, as a basis for explaining the adoption of the varietal mixture technology.

In Chapter 2, results are presented of a field experiment, conducted in Gejiu, Yunnan Province during the wet season of 2002 to elucidate the importance of resource complementarity and prevention of lodging in the technology of growing rice varietal mixtures. The hybrid rice variety Shanyou 63 and the glutinous or sticky rice variety Huangkenuo were used to study intra- and inter-varietal competition in the rice intercropping system. The results showed that resource complementarity between the two rice varieties, resulting from niche differentiation, was marginal and hardly contributed to the higher yields of the rice varietal mixtures. In contrast, prevention of lodging of glutinous rice appeared an important additional advantage of growing rice in varietal mixtures.

Chapter 3 presents an overview of the technology adoption and diffusion of mixture planting in Yunnan Province and assesses its impact on pest management and farmers' income. One hundred four farmer-adopters of mixture planting in four villages and 30 nonadopters from three villages in Shiping and Jianshui Counties, Hong He Prefecture, were personally interviewed in 2000 to collect information on household characteristics, farm management practices, input use, yield, costs, and income. Data were then analysed using 'before and after' and 'with and without' project comparisons to determine the impact of mixture planting.

Results showed that farms using varietal mixtures had a lower intensity of blast disease and in 1999, farmer-adopters on average spent US$ 10.50 ha^{-1} on pesticides compared to US$ 42.92 ha^{-1} by nonadopters. Farmer-adopters realized higher yields in 1999 than in 1996, before adoption of the rice interplanting technology. In comparison with the yield on nonadopters' farms, glutinous rice yield was 82% higher on mixture farms. The yield of hybrid rice was almost the same, even though 20% of the land was allocated to plant one row of glutinous rice between four rows of hybrid rice. Overall, yield was 7% higher and gross return 14%, since the price of glutinous rice was twice that of hybrid rice, because of its higher quality. The net gain in farm-operator surplus was estimated at 25%.

In Chapter 4, a Tobit model was used to determine the major factors that conditioned farmers' decisions to adopt rice varietal mixtures in Yunnan. Results showed that contact with extension workers and farmers' perception of the technology-specific attributes of the rice varietal mixtures were the major factors determining adoption probability and use intensity.

In Chapter 5, we analysed the effect of interplanting on technical efficiency of rice production and identified the sources of inefficiency, using a stochastic frontier production function. Results showed that adoption of rice interplanting was the major contributing factor to increased technical efficiency. Longer farming experience and access to extension agents were both significantly positively correlated with technical efficiency. The first variable might reflect the skills of a farmer to optimally allocate the resources at his/her disposal; the second variable reflects the positive correlation between access to extension agents and adoption of the interplanting technology. Separate analyses for adopters and nonadopters showed that although rice interplanting was mainly aimed at controlling blast disease, absence of the disease increased the responsiveness of output to inputs such as labour, seeds and fertilizer. This observation indicates that the improvement in technical efficiency of rice production through interplanting, basically results from positive interactions among various input factors.

Chapter 6 reviews past and current research on rice disease management with special emphasis on the role of genetic diversity in the evolution and management of rice disease epidemics. Focus is on the utilization of disease resistance genes and their contribution towards achieving sustainable crop production. With respect to breeding for resistance, attention is given to identification of the right genes and to development of strategies that optimally deploy these genes in space and time to achieve sustainability at cropping systems level. After discussing the rice interplanting experiments conducted in Yunnan, additional case studies, designed to extend the diversification concept to other diseases and cropping systems, are presented. Finally, the future prospects of exploiting plant diversity to sustain production and conserve germplasm are discussed.

In conclusion, the rice interplanting system in Yunnan has shown that it is possible to combine modern and traditional rice varieties to control blast disease, attain acceptable crop yields and provide high-quality food and income for the rural population. By re-introducing traditional varieties into a productive, but sufficiently diverse agro-ecosystem, we can harmonize *in situ* conservation with intensive production systems.

Our analysis also shows that farmers' early participation in the project is a crucial factor in showing the impact of using the technology and subsequently in its adoption. Hence, "impact must be seen, felt, and acknowledged *by farmers*, *not just by scientists*."

The Yunnan experience has demonstrated that the best way to transfer a technology from concept to actual practice is to strengthen the links among research, extension, policy makers and farmer communities.

Samenvatting

De zogenaamde Groene Revolutie, die begon in het midden van de 60-er jaren van de vorige eeuw, heeft geleid tot een geweldige toename in de totale wereldvoedselproductie, doordat boeren op grote schaal nieuwe technologieën gingen gebruiken, gestimuleerd door gunstige beleidsmaatregelen. Deze technologieën werden gekarakteriseerd door nieuwe hoogrenderende variëteiten in combinatie met opbrengstverhogende en opbrengstbeschermende inputs. Eén van de consequenties van deze ontwikkelingen is geweest dat het aantal soorten en variëteiten waarop de voedselvoorziening is gebaseerd dramatisch is afgenomen, zodat op dit moment de wereldbevolking grotendeels wordt gevoed via de productie van een beperkt aantal variëteiten van zo'n 15 gewassoorten..

Het is algemeen geaccepteerd dat deze genetische uniformiteit in de huidige agro-ecosystemen een gevaar vormt voor snelle verspreiding en uitbreiding van ziekten en plagen en gemakkelijk kan leiden tot het uitbreken van epidemieën. Om het uitbreken van dergelijke epidemieën in die uitgebreide monoculturen te voorkomen, werd intensief gebruik van pesticiden een standaardonderdeel van het gewasbeheer. Meer en meer echter werden de gevaren van het gebruik van pesticiden voor de menselijke gezondheid en voor de milieukwaliteit onderkend. Als reactie daarop, werd onderzoek gestart naar alternatieve vormen van gewasbescherming, zonder of met gebruik van heel weinig pesticiden. Eén van de benaderingen daarbij was het introduceren van biodiversiteit in gewassystemen om uitbraken van ziekten en plagen in de hand te houden.

De geschiedenis van de Pyricularia bladvlekkenziekte in de provincie Yunnan in China is één van de meest succesvolle en meest geciteerde voorbeelden van het gebruik van genetische diversificatie voor het onderdrukken van ziekten en plagen. Het vochtige en koele klimaat van Yunnan vormt een ideale omgeving voor het zich ontwikkelen van epidemieën van deze ziekte. In de loop van de geschiedenis van dit gebied zijn er dan ook ernstige uitbraken van de ziekte geweest met zware opbrengstverliezen.

Na het succes van resistentieveredeling was Pyricularia bladvlekkenziekte eigenlijk geen serieus probleem meer in de hybride *indica* rijstvariëteiten, maar het bleef een probleem in de teelt van de in China populaire kleefrijst, die voor speciale gerechten wordt gebruikt. Vóór 1998 moesten de boeren drie tot acht maal per seizoen spuiten met fungiciden om een acceptabele opbrengst van kleefrijst te halen. Om de afhankelijkheid van de boeren van pesticiden te verminderen, alsmede de aan dat gebruik verbonden gevaren, initieerde een team van onderzoekers van het International Rice Research Institute (IRRI) and Yunnan Agricultural University (YAU) een project in

Yunnan met als doel de mogelijkheden te verkennen van het gebruik van biodiversiteit om uitbraken van Pyricularia bladvlekkenziekte te voorkomen en via de daardoor gerealiseerde toename in productiviteit en inkomen, bij te dragen aan vermindering van de armoede.

De technologie die in het project werd ontwikkeld, waarbij om-en-om één rij van de hoogwaardige maar voor Pyricularia bladvlekkenziekte gevoelige kleefrijst en vier tot zes rijen tegen de ziekte-resistente hybride *indica* variëteiten werden geplant, werd heel snel en op grote schaal opgenomen door de boeren in Yunnan: het areaal groeide van 15 ha in 1997 tot meer dan 550,000 ha in 2003. Om van deze ervaring te leren moeten we het proces van de introductie van deze mengteelt en van z'n daaropvolgende opschaling begrijpen. Wat was de impact van het gebruik van de mengteelt op de door de boeren gebruikte gewasbeschermingstrategie, op de gewasopbrengst en op het bedrijfsinkomen? Wat waren de belangrijkste elementen die een rol speelden in het proces van verspreiding van de technologie? Wat waren de belangrijkste factoren die boeren ertoe brachten om de mengteelt toe te passen?

In deze studie hebben we de effecten geanalyseerd van de genetische diversiteit op de manier waarop boeren omgingen met de Pyricularia bladvlekkenziekte en de sociaal-economische effecten, met name op productiviteit en bedrijfsinkomen van het gebruik van de mengteelt als basis voor het verklaren van het opnemen van de technologie door de boeren.

In Hoofdstuk 2 worden de resultaten gepresenteerd van een veldproef uitgevoerd in Gejiu in de provincie Yunnan in het natte seizoen van 2002, om het belang vast te stellen van complementariteit in het gebruik van natuurlijke hulpbronnen en het voorkómen van legeren in de technologie van de mengteelt. De hybride variëteit Shanyou 63 en de kleefrijst variëteit Huangkenuo zijn gebruikt om de competitie binnen en tussen de variëteiten te bestuderen. De resultaten lieten zien dat de complementariteit van gebruik van hulpbronnen als gevolg van niche differentiatie van marginaal belang was, en de productiviteit van de mengteelt nauwelijks verhoogde. Daarentegen was het voorkómen van legeren van de kleefrijst wel een belangrijk toegevoegd voordeel van de mengteelt.

In Hoofdstuk 3 wordt een overzicht gepresenteerd van het opnemen van de technologie van de mengteelt en de verspreiding ervan in de provincie Yunnan, en wordt de impact geëvalueerd op het gewasbeschermingregime en op het bedrijfsinkomen. Honderd-en-vier boeren uit vier dorpen die de mengteelt gebruikten en 30 boeren uit drie dorpen die de technologie niet gebruikten in de counties Shiping and Jianshui in Hong He Prefecture in Yunnan zijn persoonlijk geënquêteerd om informatie te verzamelen over de karakteristieken van hun bedrijf, bedrijfsbeheer, gebruik van inputs, opbrengsten, kosten en inkomen. De gegevens zijn geanalyseerd via vergelijking van 'voor en na' en 'met en zonder' om de impact van de mengteelt vast te stellen. De resultaten laten zien dat op de bedrijven die gebruik maakten van de mengteelt de aantasting met Pyricularia bladvlekkenziekte minder was, en in 1999 gaven de boeren mét mengteelt gemiddeld US$ 10,50 ha^{-1} uit aan pesticiden, terwijl dat voor de boeren zonder mengteelt US$ 42,90 ha^{-1} was. De boeren mét mengteelt realiseerden hogere opbrengsten in 1999 dan in 1996. Kleefrijst bracht bij de boeren mét mengteelt 94% meer op dan bij de boeren zonder. De opbrengst van hybride rijst was praktisch gelijk, terwijl bij de boeren mét mengteelt 20% van het land (één van elke vijf rijen) werd gebruikt voor kleefrijst. De totale korrelopbrengst was 7% hoger en het bruto inkomen 14% (kleefrijst brengt twee keer zoveel op vanwege de betere kwaliteit). Het netto bedrijfsinkomen van de boeren met mengteelt werd 25% hoger geschat.

In Hoofdstuk 4 wordt het gebruik van een tobit-model beschreven om vast te stellen wat de belangrijkste factoren waren die de beslissing van de boeren beïnvloedden om de mengteelt te gebruiken. De resultaten van het model laten zien dat contact met de voorlichtingsdienst en de perceptie van de boeren met betrekking tot de specifieke eigenschappen van de technologie de belangrijkste factoren waren die de beslissing om te gebruiken en de intensiteit van gebruik van de technologie bepaalden.

In Hoofdstuk 5 is een 'stochastische frontier' productiefunctie gebruikt om de effecten te analyseren van de mengteelt op de technische efficiëntie van rijstproductie en om de bronnen van inefficiëntie te identificeren. De resultaten laten zien dat gebruik van de mengteelt de belangrijkste bijdrage leverde aan hogere technische efficiëntie. Het aantal jaren boerenervaring en contact met voorlichters waren beiden positief gecorreleerd met technische efficiëntie. Meer ervaring zou kunnen leiden tot een beter inzicht in de optimale verdeling van de beschikbare hulpbronnen, terwijl de positieve correlatie met het contact met de voorlichtingsdienst de correlatie tussen dat contact en het gebruik van mengteelt weerspiegelt. Gescheiden analyse van de gegevens van de gebruikers van mengteelt en de niet-gebruikers liet zien dat, hoewel mengteelt vooral was bedoeld om Pyricularia bladvlekkenziekte te onderdrukken, de afwezigheid van de ziekte ertoe leidde dat de opbrengst sterker reageerde op de inputs aan arbeid, kunstmest en zaaizaad. De hogere technische efficiëntie in de mengteelt is het resultaat van positieve interacties tussen de verschillende productiefactoren.

In Hoofdstuk 6 wordt een overzicht gegeven van onderzoek op het gebied van gewasbescherming in rijst met speciale aandacht voor de rol van genetische diversiteit in de ontwikkeling en het beheer van ziekte-epidemieën. De nadruk ligt op het gebruik van resistentiegenen en hun bijdrage aan het realiseren van duurzame gewasproductie. Met betrekking tot resistentieveredeling wordt aandacht besteed aan identificatie van de juiste genen en aan het ontwikkelen van strategieën voor optimaal gebruik van deze genen in ruimte en tijd om duurzaamheid te realiseren op het niveau van gewassystemen. De proeven met mengteelten van verschillende rijstvariëteiten in Yunnan worden eerst besproken, gevolgd door bespreking van andere *case studies* die ontworpen zijn om het concept van diversificatie uit te breiden naar andere ziekten en andere gewassystemen. Tenslotte wordt gekeken naar de vooruitzichten voor het gebruik van biodiversiteit voor het handhaven van de productiviteit en het conserveren van genetisch bronnen.

Concluderend kunnen we vaststellen dat het systeem van mengteelt in Yunnan duidelijk heeft aangetoond dat het mogelijk is traditionele en moderne variëteiten te combineren om tegelijkertijd Pyricularia bladvlekkenziekte te bestrijden, acceptabele opbrengsten te realiseren, voedsel van hoge kwaliteit te produceren en inkomen te genereren voor de plattelandsbevolking. Door het herintroduceren van traditionele variëteiten in een hoogproductief en voldoende divers agro-ecosysteem kunnen we *in situ* conservering van genetisch materiaal combineren met intensieve productiesystemen. De mengteelt in Yunnan heeft eveneens aangetoond dat het van cruciaal belang is de boeren vanaf het begin te betrekken bij een dergelijk project om de impact van de nieuwe technologie te demonstreren en zodoende het gebruik ervan te stimuleren. In samenvatting, ‘impact moet worden gezien, gevoeld en geaccepteerd *door boeren, niet alleen door onderzoekers'*.

De ervaringen in Yunnan hebben aangetoond dat de beste manier om een nieuwe technologie van concept naar praktische toepassing te brengen is, het verstevigen van de connecties tussen onderzoek, voorlichting, beleidsmakers en boerengroepen.

摘要

发生在六十年代中叶的“绿色革命”带来全球粮食生产的巨大增长，这是广泛采用新技术包括高产品种、高生产投入及植物保护，配以有力政策实施的结果。但是这一农业发展的后果之一是我们赖以生存的植物种类及品种多样化同等巨大的降低，以至于目前人类生存很大程度上仅依赖于 15 个植物种的有限品种。这种当今农业生产系统中的遗传一致性被广泛认为是刺激病虫害发生并流行的主要因素。为了防止病虫害在大面积单作作物中的爆发，大量使用农药成为农作管理中的重要一环。然而，过量和滥用农药对健康和环境造成的负面作用已经引起越来越多的社会关注。为此，发展其它病虫防治系统的研究被启动。其中之一就是在作物栽培系统中有目的地引入不同物种来控防病虫害的大发生。

中国云南省利用遗传多样性控防水稻稻瘟病就是一个最成功也广为人知的实例。云南的湿冷气候非常适合水稻稻瘟病的发生。历史上稻瘟病的流行发生曾造成云南严重的粮食减产。通过成功的抗病育种，杂交籼稻上的稻瘟病已经不再是生产上的大问题；但对人民喜爱的糯稻，稻瘟病问题依然严重。在 1998 年之前，农民每季糯稻要喷三到八次农药才能有所收成。为了减少农业生产对农药的依赖，一支由 IRRI 和云南农大组成的科研队伍在云南实施了一个研究项目，目的是研究利用生物多样性控防稻瘟病并因此增产增收以帮助脱贫的可行性。

本项目研究发展的“间栽”技术，即每四至六行主栽杂交籼稻插入一行优质但感病的糯稻，被云南农民很快接受并大面积推广：由 1997 年的 15 公顷发展到 2003 年的 550,000 公顷。为了学习这一经验，我们必须搞清楚“间栽”技术的引介及推广过程。“间栽”技术对病害防治、作物产量和农民收入有哪些影响？哪些是技术传播的重要因素？哪些是支配农民决定采纳品种“间栽”的重要因子？

该论文研究分析了遗传多样性对稻瘟病防治的影响，并确定了以利用遗传多样性为基础解释品种混种技术推广的社会经济学，即生产力和收入。

第二章报告了 2002 年雨季我们在云南“个旧”进行的田间试验结果，阐明了品种间栽对资源互补及防止植株倒伏的重要性。杂交稻“汕优 63”和糯稻“黄壳糯”用来研究作物间栽系统中种内与种间的竞争。结果显示，这两个品种间由群体特性差异带来的“资源互补”是很有限的，且未显著增加产量；相比之下，防止糯稻倒伏则成为间栽杂交稻与糯稻的一个优点。

第三章论述了云南省水稻“间栽”技术的传播及推广形势，并评估了这一技术对病虫害防控及农民收入的影响。在 2000 年，我们访问调查了“石平”与“剑水”两县四乡镇 104 个使用间栽技术的农户和 30 个未使用该技术的农户，收集了有关农户特

征、农业管理方式、农业投入、产量、花费及收入方面的资料，然后进行“之前”与“之后”及“有”与“无”之间的分析比较以确定“间栽”的效应。结果显示，在 1999 年使用“间栽”技术的稻田中稻瘟病发病率下降；采用该“间栽”技术的农民平均每公顷投入 10.50 美元农药费，而未采用此技术的农户则每公顷投入 42.92 美元农药费。采用此技术的农民在 1999 年获得了比在 1996 更高的产量。相对于未采用此技术者，采用者多收糯稻 84%；虽然间作方式下实际杂交稻面积因间套糯稻比单作方式下少了 20%，但两种种植方式下杂交稻的产量几乎相同。综合看，“间栽”技术带来 7%的稻谷增产或 14%经济增收。增收大于增产是因为糯米比杂交稻贵两倍。以总体水稻生产产值而言，“间栽”技术采用者较未采用者净增收 25%。

第四章叙述了用“Tobit”模型确定决定云南农民采用“间栽”技术的主要因子。结果说明“与推广人员接触”与“农民对这一技术的理解”是决定该技术采用率与应用强度的主要因素。

第五章利用随机前沿生产函数分析了“间栽”对水稻生产技术效率的影响，并认定了无效因素。结果显示技术采纳是提高技术效率的主要因素。“长期农作经验”和“与推广人员接触”都显著正相关于技术效率，前者可能反映了农民优化资源分配的能力，后者则反映了“技术获得”与“技术采纳”正向相关。对采用及非采用该技术的农民情况分别分析显示，尽管“间栽”是针对防控稻瘟病的技术，但对植物病害的有效控制激发了更多的生产投入，如劳动力，种子及肥料。这一结果说明，通过“间栽”而提高的水稻生产技术效率是由各种投入的正向效应共同导致的。

第六章回顾了过去与当前在水稻稻瘟病控防方面的研究，重点是“遗传多样性”对稻瘟病发生流行的演变及控防的作用，焦点是抗病基因的利用及其对可持续作物生产的贡献。在抗病育种方面，注重鉴定“抗病基因”并发展策略以在时空上合理使用这些基因，从而实现农作水平上的可持续生产。本章除了讨论在云南进行的水稻“间栽”系统外，也讨论了“生物多样性”在其它病害及种植系统方面的应用研究。最后讨论了应用“生物多样性”实现可持续生产及种质资源保持的前景。

结论：云南的水稻“间栽”系统清晰表明，用“现代”与“传统”品种间作的方法以控防稻瘟病、获得可接受的产量水平、提供更多的优质粮食和更高的收入是可行的。把传统老品种间套进高产品种的田块中，实现了在高产系统中对种质资源的保护。这一研究还显示，农民在一个研究项目中的早期参入对技术的采用及推广是非常关键的。因此说，“成果要能让农民，非但是科学家眼见、感觉及认同”。云南经验还表明，一个技术从概念转化为实用的最佳途径是加强研究推广工作与政策策划者和农民社区的联系。

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- Competitive relations within rice mixtures system in Yunnan; Yunnan Agricultural University (YAU) (2002 and 2003)

Post-Graduate Courses (4.2 ECTS)

- Qualitative dependent variable, limited dependent variable and multivariate statistical models with applications to modelling adoption of new technologies; IRRI-UNE, Australia (2001)
- Operational tools for regional land use analysis: PE&RC (2001)

Deficiency, Refresh, Brush-up Courses (5.6 ECTS)

- Systems analysis and systems design in crop protection; CWE (2001)
- Basic statistics; PE&RC (2001)
- Basic experimental design and data analysis; IRRI (2004)

Competence Strengthening / Skills Courses (5.2 ECTS)

- Scientific writing; PE&RC (2001)
- Presentation skills; IRRI (2002)
- SAS Training Course; IRRI (2005)
- SPSS Training Course; ACER-Philippines (2005)
- STATA Training Course; IRRI (2008)

Discussion Groups / Local Seminars and Other Scientific Meetings (6.8 ECTS)

- Plant and Crop Ecology (Kropff, Bastiaans) (2001)

- IRRI Thursday Seminar (2001–2008)
- Biodiversity for Pest Management: It's All in the Mix - IRRI Thursday Seminar Speaker (2004)
- Celebrating Nationally Recruited Staff Excellence - IRRI Thursday Seminar Speaker (2006)
- CWE and PPS Lunch Seminars (2008)
- International Workshop on Impact Pathways (2008)

PE&RC Annual Meetings, Seminars and the PE&RC Weekend (1.4 ECTS)
- PE&RC Winterschool on functional biodiversity for sustainable crop production (2001)
- PE&RC Facilitation seminar on stakeholders' participation (2008)

International Symposia, Workshops and Conferences (10.8 ECTS)
- Impact Symposium on Exploiting Biodiversity for Sustainable Pest Management; Kunming, China; invited speaker (2000)
- First International Rice Research Conference; Beijing, China; invited speaker (2002)
- International Training Course on Application of Participatory Approaches to Agricultural Research and Extension; IRRI, Philippines; invited speaker (2005)
- International Conference on Agricultural and Rural Development in Asia: Ideas, Paradigms, and Policies Three Decades After; Manila, Philippines (2005)
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- International Forum on Rice Policy Research: Key Issues from National Perspective; IRRI, Philippines (2008)

Curriculum vitae

Imelda Marfori Revilla-Molina was born on 4 May 1962 in Manila, Philippines. She received her B.S. (1983) and M.S. (1990) degrees in agricultural economics from the University of the Philippines at Los Baños (UPLB). She joined the Center for Policy and Development Studies at UPLB in 1984, where she worked on the economic analysis of capture fishery activities in Lake Bato and Lake Buhi, Bicol Region. In 1985, she started her MSc studies on a part-time basis and worked as research assistant in the Winrock International-SEARCA project on economic analysis of crop-animal on-farm research and extension. She was a recipient of the Asian Development Bank Research Fellowship (1986–87) for her study on the economic evaluation of azolla use by rice farmers in central and southern Philippines. In 1988, she joined the Philippine Rice Research Institute, where she worked on the socio-economic evaluation of national rice-based research and development programmes. Four years later, she joined the International Rice Research Institute as Senior Research Assistant-cum-Program Assistant of the Cross-Ecosystems Research Program. In addition to programme management, she was involved in research on priority-setting in the Cross-Ecosystems Program in collaboration with other ecosystem-specific programmes and NARS, and conducted studies on evaluating the rice research capacity of Asian NARS. She was hired as an Associate Scientist in the Social Sciences Division at IRRI in August 2000, where she provided technical support in planning, conceptualization and implementation of research on the economic and environmental impact of rice varietal diversification through gene deployment for sustainable pest management and on the biotic constraints to increasing rice production through identification and assessment of technological needs and constraints of rice farmers. In December 2000, she started a Sandwich-PhD Programme in the Plant Production Systems (PPS) and Crop and Weed Ecology (CWE) Groups of the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) of Wageningen University. The research output under this scholarship is described in this thesis. In 2002, she was the lead member of the nationally recruited staff from IRRI that won the CGIAR Outstanding Scientific Support Team Award for the project entitled “Exploiting Biodiversity for Sustainable Pest Management.” She is married to Agustin B. Molina Jr. with whom she has a son, Justin.

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