CULTIVATING BIODIVERSITY FOR DISEASE CONTROL, A CASE STUDY IN CHINA

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Abstract

Diversifying Rice varieties for controlling the disease called Blast in farmers' field were assessed. Large-scale field tests for two consecutive years showed that the highly susceptible glutinous Rice varieties (Huangkenuo and Zinuo) suffered less disease when inter-planted with the generally resistant indica hybrid varieties (Xianyou 63 or Xianyou 22). The field design was a repeating pattern of one row of glutinous Rice inter-planted with four or six rows of indica Rice. Helped by a vigorous extension campaign, farmers in Yunnan rapidly adopted the scheme, with area planted to mixture now covering 47,667 hectares. This rapid adoption can be attributed to strong support from technicians and leaders of counties, relevance to the needs (problems) of farmers in the area, simplicity and effectiveness of the technology, and improvement in the yield and income of farmers. Plans are now in place to implement the technology to other provinces of China, and to widen the options for varieties that can be used for diversification. Biodiversity is a practical tool in place of crops with restricted genetic diversity and an economically viable option for farmers who cannot afford patented commercial varieties. It also supports the retention of the rich variety of farmers' landraces.

Introduction

Yunnan Province is in Southwest China, located from 20 to 29 degrees north latitude and from 97 to 196 degrees east longitude. It has an area of about 383 thousand square kilometers (sq. Km). The elevation for planting rice is highest at 2700 m at Lin Lang County, and lowest at 76 m at Hekou County. There are many plains on the Yunnan plateau. These plains are the main places for agriculture, especially for Rice production. There are 1442 plains, most of which are small (about 1 square km); and only 47 plains are big plains, each is more than 100 sq. km (Jiang 1994).

Blast is the main disease of Rice in Yunnan. The fungus that causes Blast disease, *Magnaporthe grisea*, spreads through multiple cycles of asexual conidiospore production during the cropping season, causing necrotic spots on leaves and necrosis of panicles(Zhu 2000). The wet, cool climate of Yunnan Province is highly favorable for

development of Rice Blast epidemics. Throughout the history of Rice cultivation in this area, Blast outbreaks have caused serious losses. Crop losses due to Blast accounted for 91%, 96.6% and 98.6% of total disease losses in 1974, in 1978 and in 1990, respectively. Generally, the average loss per year for a 21- year period (1971 to 1992) was 57.8% of total disease losses.(Li Chengyun 1994)

Because of the incorporation of resistance genes, Rice Blast is no longer a serious problem for the widely grown hybrid indica Rice. However, it has remained a serious problem for glutinous Rice (32% losses), japonica Rice (5-12% losses) and upland Rice (losses could reach to 20-50%). Farmers growing these susceptible varieties use fungicide to control Blast, making as many as three to eight spray applications per season (Li Jiarui 1994).

It is now widely recognized that increasing the intraspecific genetic diversity of crop populations provides an ecological approach for suppression of epidemics. Deployment of multilines or mixtures of varieties has been successfully used to manage serious diseases of some cereals such as stripe rust of Wheat and powdery mildew of Barley in commercial scale(Browningg and Frey 1969, Wolfe 1985, Mundt 1994, Garrett 1999). Based on this knowledge, and drawing from the experiences of our own farmers, we experimented with a diversification approach to control Rice Blast. In this presentation, we will describe the result of mixture experiments, the current status of mixture planting by farmers, and the prospects of mixture planting in other provinces of China.

Beginning and Early Results of Diversification Project

When we started this project in 1997, a number of diversification approaches were considered, including seed mixture and planting different varieties in adjacent fields. Farmers, however, did not like the idea of seed mixture. We eventually set up an inter-field diversification experiment in Bao Xiu, Shiping County which was very similar to one was done by local farmer in 1980-84. Each farmers field of about 667 sq meter was considered as one plot. We took 3X5 rows of adjacent plots and planted a different variety in each plot. The result were not very good. Disease was severe in plots where susceptible varieties were planted. At about the same time in 1997, a similar experiment was conducted in Zhang qui zhai, also in Shiping County. The farmers, however, modified the design. Drawing from their own experience, diversification was done within farmers field. Rows of the susceptible glutinous variety were planted in every four rows of the relatively resistant indica Rice in a repeating pattern throughout the field. The result was remarkable. The mixture of glutinous varieties (Huangkenuo or Zinuo) with indica hybrid varieties (Shianyou 63 or Shianyou 22) significantly reduced the incidence and severity of the Rice Blast disease. Apparently, farmers in this area had been interplanting susceptible glutinous Rice among the relatively resistant indica Rice to escape from serious Blast disease since about 1983, although in very limited scale and a somewhat random or irregular pattern.

Large Scale Field Trials

In 1998, mixtures of varieties were planted in a 812 ha area comprised that all Rice fields in five townships (Baxing, Baoxiu, Songchun, Maohe, and Yafanzi) of Shiping County, Yunnan Province. Four different mixtures of a glutinous and a hybrid variety

were planted within this area. Rice fields were managed by farmers, using agronomic practices that are standard for the area. For mixtures, the same row spacing of hybrid Rice was used as in monoculture, the row spacing distance between two rows of hybrid Rice were 15 cm, and between the two rows and other two rows were 30 cm, but one row of glutinous Rice was added between each group of four to six rows of hybrid Rice, in an "addition" approach (Fig. 1).

Fig. 1. Rows of glutinous Rice variety interplanted among rows of hybrid indica variety in a repeating pattern of one row of glutinous for every 4-6 rows of hybrid Rice .

To monitor disease, survey plots were established at fifteen sites, three in each of the five townships participating in the diversification program. All plots were treated in the same manner as the surrounding mixed variety plantings, including fungicide application Row spacings were those commonly used by Rice farmers in Yunnan Province (Fig. 1). In each of the 15 survey sites, a field was divided into three plots. One plot was planted to the mixture that was being grown most commonly by local farmers, while the remaining two plots were monocultures corresponding to the glutinous and hybrid variety that was included in that mixture. Plots ranged from 100 to 450M^2 each, depending of field size.

No fungicides were applied to control leaf Blast in the survey plots. However, a one time spray for neck Blast was done for the rest of the demonstration plots. Survey plots were assessed for the severity of Blast symptoms, expressed as the percentage of panicle branches that were necrotic.

The mixture planting area was expanded to 3, 342 ha of Rice fields in 1999. This area consisted of all Rice fields in 10 townships that spanned Jianshui and Shiping Counties, with five participating townships per county. Procedures were identical to the 1998 experiment, except that no foliar fungicide applications were made for either leaf or panicle Blast. In addition, some farmers chose to plant mixtures in a ratio of 1:6 glutinous: hybrid, rather than 1:4. There were 15 survey sites per county (three in each of the five townships).

Results

Mixture planting had a substantial impact on Rice Blast severity and yield. In the 1998 planting in Shipping, panicle Blast severity on the susceptible, glutinous varieties was 94 to 99% less severe when grown in mixture than when grown in monoculture. Panicle Blast on the more resistant, hybrid varieties was 1 to 25% less severe in mixed plots than

in the monoculture plots, despite the fact that hybrids were planted at the same density in both mixture and monoculture survey plots.

Results from 1999 were very similar to the 1998 season for panicle Blast severity on the susceptible varieties, showing that the impact of diversification was very robust among mixtures and between seasons and counties. In contrast, impacts of crop diversification on Blast severity of the hybrid varieties were larger in 1999 than in 1998, with panicle Blast severity averaging 59% less in mixed populations than in monoculture. By the second year of the project, no foliar fungicides were needed for Blast control in the diversified area. Though elimination of foliar sprays may not be possible in all seasons, varietal diversification can clearly result in a very substantial reduction of fungicide use, The mixture, or inter-plantings, of hybrid and Glutinous varieties did not only reduce the production loss caused by Rice Blast, but increased total Rice yield per hectare compared with the monoculture field. The average yield of the mixture planting of Xianyou 63 with Huangkenuo was 10533.1 kg and more 825.8 kg than that of pure-cropping of Xianyou 63. The average yield of the mixture planting of Xianyou 63 and Zinuo was 10461.7 kg and more 833.9 kg than that of pure-cropping of Xianyou 63. The average yields of mixture planting of Xianyou 22 with Huangkenuo and Xianyou22 with Zinuo were 9996 kg and 9993 kg, more 916.8 kg and 852.5 kg than the pure-cropping of Xianyou22 respectively.

Current Status

The Yunnan diversification program has resulted in great interest by farmers, and a commitment from government officials to help expand the practice. At the start of the 2000 cropping season, the interplanting scheme was implemented in 47,667 ha in 40 counties in Yunnan (Figure 2). The results showed that panicle Blast severity on the susceptible, high-quality varieties was 86.2 to 99.8% less severe when grown in mixture than when grown in monoculture. Panicle Blast on the more resistant indica (hybrid) varieties was 34.9 to 52% less severe in mixed plots than in monoculture.Only in Yunnan province, the farmers have got 36000,000 kg high-quality Rice and more US$8.43 millions than the pure-cropping this year.

The rapid adoption of the mixture planting technique can be attributed to a vigorous and systematic knowledge dissemination scheme. At the county level, the first step was to hold a meeting with county government officers including the vice mayor in charge of agriculture, chief of county science and technology commission, and chiefs of plant protection and agro-technology stations. Once support is received from these officers, the next step was to conduct a workshop with the technicians in agricultural technology and plant protection county offices. These trained technicians then organized small group discussions among farmers through the village officers. During planting time, the more skilled farmers took the lead to demonstrate to other farmers, and the agro-technicians acted as supervisors. This year alone, we have held 53 regular training courses for about 400 agricultural technicians from various plant protection stations of Yunnan province and other provinces. More than 7,000 farmers have been subsequently trained in echo seminars and field demos. Other extension methods include providing

video clips to local cable television network. Which were usually shown during commercial breaks of popular television programs.

Prospects and Future Plans

Expansion to other provinces in China. The area covered by mixture planting is expected to expand beyond Yunnan province. The Ministry of Science and Technology is keen to extend the germplasm diversification approach for Blast control to other provinces because this project fulfills the purpose of the Chinese Central Government's Poverty Alleviation Program for the South-west and North-west. An agreement on mixture planting demonstration has been signed with nine other provinces of China, namely Sichun, Chongqing, Hunan, Hubei, Jiangxi, Guangdong, Jiangshu, and Zhejiang (Fig. 3).

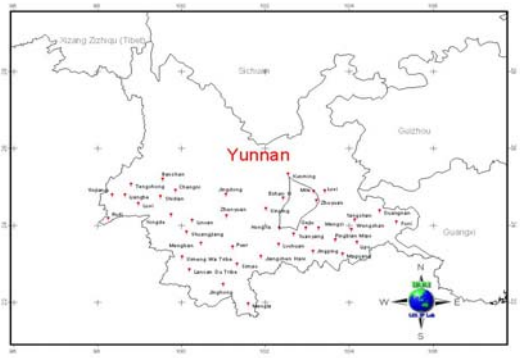

Fig 2. Counties in Yunnan province covered by the diversification scheme during the 2000 crop season.

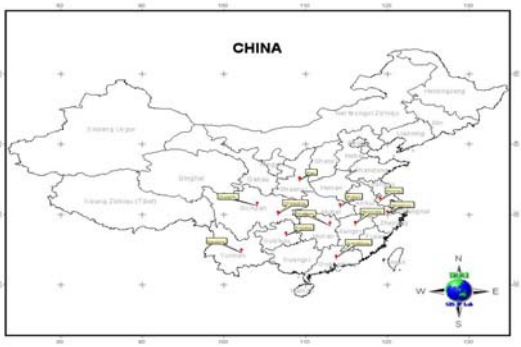

Fig 3. Provinces in China where demonstration trials for mixture planting have been done in 2001. (the map of China is a sketch map)

Testing new varieties and crops suitable for mixture.

As the area covered by the mixture planting scheme expands, it becomes necessary to introduce additional diversity into the system to preclude pathogen adaptation that might lead to disease outbreak in the future. We have screened 208 varieties for functional diversity using both field data and molecular data generated in our laboratory using RGA-PCR tools (Resistance Gene Analogue – Polymerase Chain Reaction). Twenty new Rice varieties including high-quality Rice have been included for new mixture inter-planting trials. We have also started evaluating the agronomic performance of eleven high quality aromatic Rice varieties for possible inclusion in the mixed planting. As of now, varieties are rarely planted now because they are highly susceptible to Blast.
We are also evaluating various mixture combinations of japonica by other japonica varieties. Because of the substantially larger area planted to japonica varieties than glutinous varieties, developing an effective diversification scheme for japonica varieties is expected to bring greater impact than the current success in the mixture planting of indica by glutinous varieties.

As of 2001, mixed planting of rice varieties to control blast and improve yield has covered 107,400 ha in Yunnan province. This rapid expansion can be attributed to a systematic extension campaign involving county and village officials, researchers and extension workers. The extension network ensures that not only would farmers be trained, but that seeds would be available during planting time.

It is significant to note that not only did the area increase but also the number of varieties used in mixture. Farmers began planting 26 other high quality but blast susceptible traditional rice varieties in lieu of glutinous rice as susceptible interplant to hybrid rice with equally good results. This implies that many high quality traditional varieties that are no longer planted because of susceptibility to diseases can be brought back into production through an ecological approach to crop management.

Ten other provinces in China had evaluated the technology for possible large scale implementation. Sichuan province, the third major agricultural province in China with more than 2.3 million hectares of rice evaluated the technique in over 3,000 ha in 2001. Because of the prolonged drought experienced in Sichuan this year, blast incidence was generally low even in susceptible checks. However, the yield in mixture planting was 0.50 to 1.00 ton per ha higher than growing hybrid rice alone. Monocultured glutinous rice lodged after a rainstorm while those grown in mixture escaped lodging. An expansion area of close to 70,000 ha is being planned for 2002.

We have since extended the idea of diversification to control diseases and insect pests of other major crops in Yunnan, particularly wheat and broadbean. Wheat is planted during winter in over 250□000 ha in Yunnan as part of the rice-wheat cropping system. Wheat stripe rust caused by *Puccinia triticana* is a major constraint to production, causing as much as 15-20% yield loss. Broad bean on the other hand is an important cash crop planted during the same season as wheat. Bean yield is often compromised by the serious root and stem damage caused by maggots of the bean fly (*Ophiomyia phaseoli*). We intercropped wheat and broad bean by planting wheat in blocks of 1m x 20m and then planting two rows of broad bean, in between two blocks. This intercropping design reduced the incidence of wheat rust by 19-27 %, and damage due to bean stem maggot decreased to minimal. The intercrop registered a 24-26% yield advantage over the monocrop at all sites. Rhizobial nodule formation in intercropped broadbean was also significantly higher than in the monoculture crop. An extensive network of researchers and extension personnel is being formed in Yunnan to disseminate this technology to farmers.

Understanding the mechanism of disease control in mixture.

We are also seting up a few important experiments in the field and in our Lab. to find out why some varieties are effective in mixture and others are not, and also the potential mechanism of Blast control using inter-planting, such as micro-climatic changes, spore dispersal and induced resistance. Understanding this mechanism will enable us to predict the sustainability of the system. (some problems have been to deal with, but some not yet, these mechanism will be published in other papers)

The use of patented commercial varieties is spreading, displacing traditional farmers' landraces developed over the centuries. The patented seed varieties cost more, may have restrictions on using the seeds of the resulting crops, and require higher application rates of pesticides and fertilizers. Those factors make it difficult for low-income farmers to afford. It may also require higher expenditures of hard currencies by developing countries. The biodiversity approach discussed in this paper reduces those problems. In addition it provides encouragement for the conservation of traditional landraces in local, regional and national seedbanks.

Conclusion

Among the knowledge that can be derived from the implementation of this project, three important lessons stand out. First, our results support the view that crop diversification can provide highly effective disease suppression when practiced at a large spatial scale (Wolfe 2000 and Zhu 2000). Second, our results demonstrate that collective efforts from groups of scientists, institutions, and farmers are vital to the development and dissemination of an effective diversification technology. And finally, wide adoption of a diversification technology depends on simplicity, effectiveness, and ability to bring about obvious economic benefits to farmers and to developing countries foreign exchange balances.

The diversification concept has spread to other rice growing countries as a means to sustain productivity. Field trials to evaluate the effectiveness of varietal mixtures in reducing the severity of tungro disease are underway in the Philippines. Vietnam will be trying it out on rice blast which is becoming serious in the Mekong Delta and Central Vietnam due to breakdown in resistance of the commonly grown varieties.

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References

Browning, J.A. & Frey, K.J. Multiline cultivars as a means of disease control. *Annu. Rev. Phytopathol.* 7, 355-382 (1969).

Garrett, K.A. & Mundt, C.C. Epidemiology in mixed host populations. *Phytopathology* 89, 984-990 (1999).

Li Chengyun Diseases, insect pests and weeds of Rice. *Yunnan Rice.* 1, 29-34 (1994).

Li Jiarui. Breeding for blast resistance in keng Rice. *Yunnan Rice.* 2, 122-129 (1994)

Jiang Zhinong. Geographic and climatic characteristics and rice regional division. *Yunnan Rice.* 1, 5-11 (1994).

Mundt, C.C. in *Rice Blast Disease* (eds Zeigler, R.S., Leong, S.A. & Teng, P.S.) 293-308 (CAB International, Wallingford, 1994).

Wolfe, M.S. The current status and prospects of multiline cultivars and variety mixtures for disease resistance. *Annu. Rev. Phytopathol.* 23, 251-273 (1985).

Wolfe, M.S. Crop strength through diversity *Nature* 406, 681-682(2000).

Youyong Zhu *et al.* Genetic diversity and control disease in Rice. *Nature* 406, 718-722(2000).

For Further Reading

Baker, B., Zambryski, P., Staskawicz, and Dinesh-Kumar, S.P. Signaling in plant-microbe interactions. *Science* 276, 726-733 (1997).

Browning, J.A. & Frey, K.J. in *Strategies for the Control of Cereal Disease* (eds Jenkyn, J.F. & Plumb, R.T.) 37-46 (Blackwell, Oxford, 1981).

Chin, K.M. & Wolfe, M.S. Selection on *Erysiphe graminis* in pure and mixed stands of barley. *Plant Pathol.* 33, 89-100 (1984).

Dennis Normile. Variety spices up Chinese Rice yields. *Science* 289, 1121-1122 (2000).

Dwyer, G., Elkinton, J.S. & Hajek, A.E. Spatial scale and the spread of a fungal pathogen of gypsy moth. *Am. Nat.* 152, 485-494 (1998).

Finckh, M.R. & Mundt, C.C. Stripe rust, yield, and plant competition in wheat cultivar mixtures. *Phytopathology* 82, 905-913 (1992).

Francis, C.A. in *Multiple Cropping Systems* (ed Francis, C.A.) 1-19 (MacMillan, New York, 1986).

Kiyosawa, S. Genetics and epidemiological modeling of breakdown of plant disease resistance. *Annu. Rev. Phytopathol.* 20, 93-117 (1982).

Mann, C. Reseeding the Green Revolution. *Science* 277, 1038-1042 (1997).

Matson, P.A., Parton, W.J., Power, A.G. & Swift, M.J. Agricultural intensification and ecosystem properties. *Science* 277, 504-508 (1997).

Mundt, C.C & Browning, J.A. in *The Cereal Rusts, vol. 2* (eds Roelfs, A.P. & Bushnell, W.R.) 527-560 (Academic, Orlando, 1985).

Ou, S.H. Pathogenicity and host plant resistance in Rice Blast disease. *Annu. Rev. Phytopathol.* 18, 167-187 (1980).

Staskawicz, B.J., Ausubel, F.M., Baker, B.J., Ellis, J.G. & Jones, J.D.G. Molecular genetics of plant disease resistance. *Science* 268, 661-667 (1995).

Tilman, D. The greening of the green revolution. *Nature* 396, 211-212 (1998).

Waide, R.B. *et al.* The relationship between productivity and species richness. *Annu. Rev. Ecol. Sys.* 30, 257-300 (1999).

Wolfe, M.S. in *Barley Genetics VI* (ed Munck, L.) 1055-1067 (Munksgaard, Copenhagen, 1992).