Agrodiversity for *in situ* Conservation of Thailand's Native Rice Germplasm

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ABSTRACT

The spread of modern crop varieties has led to a concern about genetic erosion and decline in local crop genetic diversity. To preserve genetic resources it is now generally accepted that in situ conservation is required along side with ex situ conservation. Conservation of natural species of plants and animals may be achieved by conserving their natural habitats. Agricultural environment, however, is influenced by rapidly evolving social and economic forces and continuously emerging technological innovations. The same principles for conserving natural species cannot be applied to in situ conservation of crop diversity. Genetic systems of crop species are also highly dynamic, subject to selection pressure driven by increasingly precise tools for genetic management, including modern biotechnology, changing human needs and preferences. It is unrealistic and unjust to expect farmers to keep their traditional crop varieties in a state of suspended animation. Sustainable and equitable conservation of crop genetic diversity on farm requires two basic sets of understanding. The first is related to the structure and dynamics of the genetic system. This will help to determine (i) what may not be worth the cost of saving and what may worth conserving almost at any cost, and (ii) in what direction future changes may be expected in the germplasm so that management strategies may be adjusted accordingly. The second is related to how farmers manage and make use of local crop varieties. Biophysical differences and the many changing ways in which farmers manage diverse genetic resources and natural variability and their practices in dynamic social and economic context characterize the agricultural environment, or niche, in which crop diversity is to be conserved. Variation in both the genetic system and the niche need to be considered at various organizational levels, from the broadest global level to regional, national, down to local village, farm, field and individual plants. This paper presents the idea of "agrodiversity", as a means to analyze and understand Thai rice farmers' innovation and management of their cropping systems and crop genetic resources. Through agrodiversity analysis, which focuses on the dynamic variation in cropping systems, output, and management practice that occurs within and between agroecosystems, niches for diversity in the local rice genetic resources may be identified and enhanced on farm.

IN SITU CONSERVATION OF LOCAL CROP GENETIC RESOURCES

Widespread adoption of modern high yielding crop varieties has led to a concern about erosion in local crop genetic resources and loss of diversity. Replacement of older varieties by modern improved varieties has accelerated in the past 50 years in what is now commonly known as the Green Revolution. High Yielding Varieties (HYVs) of rice has almost completely replaced traditional varieties in most rice growing countries in Asia (Kaosa-ard and Rerkasem, 2000). Erosion of local crop germplasm has also resulted from complete change in land use systems. Upland rice, usually grown in some form of shifting cultivation in the mountainous region of mainland Southeast Asia, is rich in genetic diversity (e.g. see Fu and Chen, 1999; Gong et al., 2001; Rerkasem et al., 2002). Land use changes, to wetland rice, extensive plantations of cash and export-oriented tree and industrial crops and large-scale vegetable production, have all resulted in losses of local varieties from farmers' fields.

Responding to this concern, conservation efforts were at first directed at *ex situ* conservation. Seeds of the world's major food crops were collected from throughout the world and preserved at international centers belonging to the CG system (the Consultative Group for International Agricultural Research, also known as the CGIAR) and various other national and international facilities. From the late 1980's weaknesses in the *ex situ* conservation began to be identified. Some pointed out that the evolutionary process that gave rise to genetic diversity is stopped in the cold storage of *ex situ* conservation (Harris, 1989). Many were also worried about the concentration, and thus control, of agricultural genetic resources in developed countries and international centers, and the lack of recognition of the contributions of developing countries and farmers (Fowler and Mooney, 1990). *In situ* conservation is seen by many to be the answer to these problems, and has since received much attention and efforts (e.g. see Smale, 1998; Brush, 1999; Almekinders and De Boef, 2000).

According to the United Nations Convention on Biological Diversity (UN CBD), *in situ* conservation of germplasm involves "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties" (Reid et al., 1993). For natural populations of wild species, which have reached a steady state or "climax" in a given environment, preserving the environment would then maintain the habitat and so conserving the populations. Throughout the 1990's much efforts and resources have been expended towards *in situ* conservation of crop germplasm as if they were wild species, but it is becoming increasingly clear that this has not worked (Louette, 1999; Almekinders and De Boef, 2000; Julian Berthaud, in CIMMYT, 2001).

To preserve "domesticated or cultivated species, in the surroundings where they have developed their distinctive properties" is to ask farmers to keep their cropping systems in the state of suspended animation. This is unrealistic as well as unjust. It may be possible to provide redress to the economic equity problem by paying farmers to keep their old cropping systems and their traditional varieties. However, such a system of *in situ* conservation will serve no different purpose from the *ex situ* conservation system, but with an added burden of much more complicated management logistics. Furthermore, it has been argued that past evolution of diversity may not be reproduced in such "museum farms", and any genetic changes that may take place in them may be totally irrelevant to future needs (Holden et al., 1993).

Agricultural germplasms are shaped by social and economic as well as biophysical factors. Agricultural habitats and selection pressures are very different from natural ones in that they are continually modified by management decisions of individual farmers responding to various socio-economic and physical factors and technological breakthroughs. Agricultural habitats are also changeable in a time frame that is much shorter than in natural ecosystems. They can also be highly fragmented into many different niches, often even on single farms, where different genotypes may exist side by side for managerial as well as ecological reasons. Crop genetic systems are subject to the process of human selection and manipulation, which have become most precise and drastic with the advent of molecular biology and genetic engineering. The comparative advantage of *in situ* conservation lies in the capacity of *in situ* populations to store large number of alleles and genotypes (Brown, 1999).

High Yielding Varieties (HVYs), the hallmark of the Green Revolution, are now grown in almost all of the rice cultivating countries of Asia, from China, India, Indonesia, Malaysia, Philippines to Vietnam. Rice yield in individual countries has doubled or tripled, but at the cost of local rice varieties being almost completely replaced by modern HYVs. Thailand is an exception, the new HYVs make up only 20% of its main rice crop, local rice varieties are still grown in farmers' field in many areas of the country. Local rice varieties remain a key component of many rice-based agroecosystems in the country, especially in the North. Northern Thailand lies in the heart of the primary centre of diversity for rice, which extends over remote mountainous neighbouring areas of India, Myanmar, China, Laos and Vietnam. The region is of strategic importance for sustainable management of the world rice genetic system. As Thailand moves along its path in development, even with occasional stumbling like the economic crisis of 1997, the key question for *in situ* conservation is whether there is room for it in the country's rice fields of the future. To answer this we suggest looking at (a) niches for different rice varieties in Thailand's rice-based cropping systems, and (b) structure and dynamics in the local rice genetic systems.

THE NICHE FOR LOCAL RICE GENETIC RESOURCES IN THAILAND'S RICE-BASED CROPPING SYSTEMS

A survey by the Office of Agricultural Economics found over 10 million rai (1.6 million ha) of traditional rice varieties still grown throughout the country in 1996 (Table 1). For efficiency in the production system as well as long term prospect for *in situ* conservation it will be useful to identify how much of the current traditional rice area has resulted from inertia in the extension process and how much has resulted from real biophysical, economic and social constraints. The rice area under traditional varieties is spread through all the four regions (Table 2). Before lack of availability and access to improved varieties is considered as the reason for persistence of traditional varieties, it should be pointed out that research stations or centres of the Thai Rice Research Institute have been located in many of these provinces for half a century or longer, long before the arrival of the Green Revolution in the early 1970's. Some, e.g. Chinat, Surin, Hantra in Ayuthya, and Koksamrong in Lopburi, are among the country's oldest and most famous rice research stations where several "improved" rice varieties have been developed. In other words, lack of access to "improved" varieties is not likely to be the main reason for continued use for many of the local varieties.

Table 1. Distributions of rice varieties grown in different regions of Thailand, wet season 1996.

Type of varieties	Planted area, by region *(rai)*				
	North	Northeast	Central	South	Country
Traditional	3,014,894	3,094,039	2,607,659	2,082,006	10,798,598
RD6†	2,328,716	13,630,741	3,607	23,962	15,987,026
RD15†	223,709	1,477,434	60,019	19,759	1,780,921
KDML105†	904,483	11,048,752	1,071,809	89,398	13,114,442
Selected traditional‡	2,110,234	1,235,470	1,805,123	76,423	5,227,250
HYVs	4,281,649	1,202,151	4,308,705	590,341	10,382,846
Total	12,863,685	31,688,587	9,856,922	2,881,889	57,291,083

† RD6 and RD15 are derived from KDML105 by mutation with radiation
‡ Local traditional varieties that have be selected by pure line method and released by the Rice Research Institute of Thailand.
Source: Adapted from OAE, 1998.

Table 2. Areas of traditional rice varieties in Thailand

Region: provinces	Area *(rai)*	% of rice land in region
North: Kamphaeng Phet, Sukhothai, Phitsanulok, Pichit, Nakhon Sawan, Uthai Thani, Phetchabun	2,609,751	20.3
Northeast: Loei, Udon Thani, Sakonakorn, Ubon Ratchathani, Srisaket, Surin, Burirum, Khon Kaen, Chaiphum, Nakorn Ratchasima	2,726,469	8.6
Central: Lopburi, Chainat, Ayuthaya, Nakhon Nayok, Prachinburi, Chachoengsao, Sakaew, Kanchanaburi	1,937,813	19.7
South: Chumporn, Surathani, Nakon Si Thammarat, Pattalung, Songkhla, Pattani, Narathiwat	1,743,562	60.5
Total	9,017,595	83.5†
Country‡	10,798,598	18.8

† % of traditional rice area in whole country
‡ Country total includes small areas in other provinces (< 100,000 *rai* each) not included in above total for each region, % of country rice area of 57.3 million *rai* planted to traditional varieties in the whole country

For many important food crops, numerous traditional varieties or landraces continue to be grown, often along side the HYV's (e.g. potatoes in the Andes, maize in Mexico and wheat in Turkey, cassava in Peru and sorghum in Ethiopia (see review by Brush, 1995; and more extensive reviews for rice, wheat and maize in Smale, 1998; Pingali and Smale, 2002). The last two authors argued that intensification of crop production and productivity gains do not always have to be associated with losses of genetic diversity. Brush (1995) suggested that land fragmentation; marginal agronomic condition, economic isolation and cultural preference and identity are the major reasons for the continuing use and conservation of the landraces. Some of these factors appear to be operating in the case of rice in northern Thailand (Gypmantasiri et al., 1980; Rerkasem and Rerkasem, 1984; Rerkasem et al., 1994), but there may also be other factors. The probability that a Turkish farmer will choose to grow a traditional variety of wheat or not was shown to depend on a complexity of factors including grain quality, yield risk, market opportunity, climatic constraints and agronomic consideration (Meng, et al., 1998). That the continued use and preservation of traditional crop varieties by farmers is determined by a complexity of biophysical, economic and social reasons is increasingly being accepted in the literature (Pingali and Smale, 2000).

A picture of distribution of the various rice varieties, by province, in the whole country has been provided by a survey by the Office of Agricultural Economics in 1996/97 (OAE, 1998). The distribution of major varieties and types by region is shown in Table 1, and by selected provinces in Table 3. Notable are the predominance of HYVs in some provinces, traditional varieties in others and the KDML varieties (KDML105 plus RD6 and RD15, which were derived from KDML105 by mutation) in many others. Together KDML105, RD6 and RD15 accounted for more than half of all the rice planted in the country's main growing season, and almost the entire planted area in some provinces. Wide adaptation to variation in the biophysical environment of the varieties is clearly indicated. This is further enhanced by the shorter growing season of RD15, by about 2 weeks, thus extending the niche into areas with earlier ending of the wet season. The conversion of non-glutinous KDML105 into glutinous RD6 has enabled it to fit neatly into the niche in the upper part of Northern and Northeastern Thailand where glutinous rice is the staple. Being non-responsive to fertilizer, they are usually planted with minimum inputs. All three produce quality rice which find ready markets for local use as well as for export, especially for KDML105 and RD15 which are exported at premium prices as Thai Jasmine or Hom Mali. The HYVs, on the other hand, tend to be grown in irrigated area and are given much higher inputs of fertilizers and pesticides. The average yield for HYVs is about 50% higher than traditional varieties, including the KDML types (OAE, 1998). The price for HYV rice is, however, only about half that of Jasmine rice. What conditions then describe the niche for traditional varieties that are still grown, including in irrigated areas in some provinces?

The means to analyze and understand farmer's innovation and management of their cropping systems and crop genetic resources is here termed "agrodiversity" (Brookfield, 2001). Agrodiversity focuses on the dynamic variation in cropping systems, out put, and management practice that occurs within and between agroecosystems. These may be defined as four different aspects of variations in rice-based cropping systems, namely, diversity in the biophysical environment, diversity in farmers' management innovation and diversity in institutional arrangements and diversity in the local rice genetic resources themselves.

Table 3. Distribution of major rice varieties in selected provinces, growing season 1996.

	Traditional	KDML type†	HYVs	Selected traditonal†	Total
			Area *(rai)*		
North					
Chiang Rai	83,753	860,210	47,678		991,641
Chiang Mai	31,494	392,722	8,078	84,146	516,440
Nakhon Sawan	1,039,489	185,852	970,260	95,228	2,290,829
Kamphaeng Phet	124,651	76,767	1,048,619	10,365	1,260,402
Phitsanulok	130,357	145,572	792,285	284,760	1,352,974
Northeast					
Udon Thani	131,579	1,492,798	63,065	352,501	2,039,943
Nongkai	48,104	1,048,475	40,369	29,048	1,165,996
Nakon Ratchasima	388,482	2,036,127	588,275	127,782	3,140,666
Ubon Ratchathani	162,959	2,490,683	111,376	126,789	2,891,807
Surin	473,682	2,351,466	0	0	2,825,148
Yasothorn	21,419	970,876	0	3,725	996,020
Central					
Ayuthya	354,515	0	319,345	201,250	875,110
Prachin Buri	407,390	121,808	16,054	188,928	734,180
Nakon Nayok	261,141	18,775	161,095	7,321	448,332
Kanchanaburi	163,947	10,269	197,600	3,223	375,039
South					
Surat Thani	193,677	25,117	67,179	29,670	315,643
Nakon Si Thammarat	603,207	32,116	239,749	946	876,018

† KDML105 plus RD6 and RD15 which have been developed from KDML105 by mutation through radiation
‡ Traditional varieties that have been selected by pure line selction and released by the Thai Rice Research Institute
Source: OAE, 1998.

Diversity in the biophysical environment

Rice in Thailand is grown in six basically different environment related primarily to water and sometimes temperature regimes. Upland rice is grown on dry soil. It is found from about 1,000 m in elevation in the northern part (up to 20o N) of the country down to just a few hundred meters further south (to about 14o N). Mountain wetland rice is grown in flooded soil, with water depth of 20-30 cm, in highland valleys and terraced fields at 600 › 1,000 m in elevation. Irrigated rice, for which the water depth can be controlled at 20 › 30 cm, accounts for some 25% of the country's lowland rice land. Lowland rain-fed rice is grown on relatively flat land, 400 m in elevation or lower, without water control. Drought is the primary constraint. Deep water and floating rice is grown in low-lying areas where water depth may reach several meters. These first five environments are in the wet season, with planting from May to August, harvesting from October to December. The sixth is dry season rice, grown where there is water for irrigation, from about January to June. Archeological evidence indicated that rice has been grown in the North (Gorman, 1969) and Northeast (Solheim, 1972) of the area now called Thailand for at least 6,000 years. Some of these agricultural habitats would have been in existence for at least a few thousand years. The myriad local populations of rice in each habitat would have gone through as many episodes of meiosis and recombination, and as many seasons of the evolutionary process and selection by farmers. Local populations in these major habitats may be expected to be significantly different from one another, and this would be ground to make sure that each is conserved.

While it is generally known that the high yielding potential of rice HYVs is best expressed where irrigation is available, however, the percentage of rice area planted to HYVs correlated only slightly ($R^2 = 0.36$) with the percentage of irrigated rice land in each province (Figure 1). The relationship between the proportion of rice land that was planted to traditional varieties and irrigation is even weaker ($R^2 = 0.04$). Irrigation is still probably the single most effective factor that removes variation in the biophysical environment for rice. Potential for further increase in irrigation area for the whole of Thailand beyond the current 25% is constrained by numerous economic, ecological, social and political reasons. The picture is slightly different in the highlands, where cultivation of wetland rice is seen as one of the major ways to increase productivity and sustainability of production. Support for investment for the development of highland paddy began with foreign assistance programs, and continues today.

According to the Department of Land Development, only two fifths of the country's rice land is judged suitable for rice growing, about half are only moderately suitable, the rest is affected by some serious constraints (Siamwalla and Na Ranong, 1990). For example, some 3 million *rai* of the Central Plain (Supanburi, Ayuthya, Pathumthani and Nakorn Nayok) are affected by acidity with pH up to 4.5, with another 300,000 rai of acid sulphate soils, affected by extreme acidity of pH < 4.5. In addition, variations in water depth and the timing of inundation have created an enormous diversity in water regimes in the country's river valleys such as the Central Plain (Takaya, 1987). About 5.6 million rai of land in the Northeast are affected by salt with another 16 million *rai* of rice land identified as susceptible to salinization.

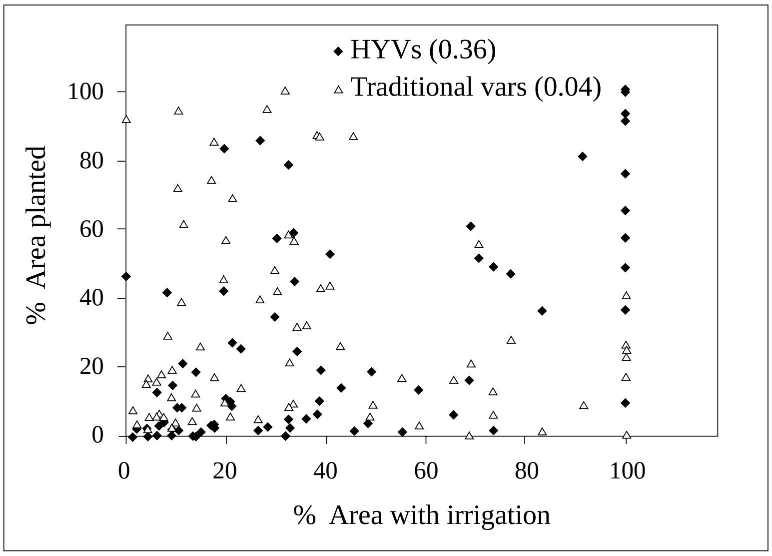

Figure 1. Relationships between percentages of rice land with irrigation and area planted to high yielding (HYVs) and traditional (Traditional vars) rice varieties in Thailand, by province (R2 in brackets).
Source: data from OAE, 1998.

In addition to these broad scale variations, farmer's choice of rice variety may be influenced by local or micro level of variations in the biophysical environment that can occur within single farms. Different varieties may be required for even small differences in water depth of 5-15 cm or delays of 2-3 weeks in field drainage at the end of the season (Rerkasem and Rerkasem, 1984). Places of great micro level variations in the biophysical environment may be found in the highlands, where differences in elevation, slope aspects and gradients and soils may occur over short distances, often within single farms. While there is yet no systematic inventory, there are many anecdotal reports of genetic richness of rice in the highlands of Northern Thailand (e.g. see Dennis, 1987; Pankao, 1996; Chantaraprayoon, 1997; Rerkasem et al., 2002). Differential adaptation in different rice varieties to these different biophysical niches is recognized by farmers. For example: *Bue Chomee* (wild fowl rice) is said to be better adapted to lower temperatures of highland paddies some varieties are more responsive to the improved condition of residual fertility and weed control in rotation with cabbage. Akha rice is believed to be good for poor soils. And so on (Rerkasem et al., 2002). Although less than 1% of the country's rice crop is grown in the mountainous highlands, highland rice is therefore of special importance to *in situ* conservation of Thailand's native rice genetic resources.

At the broad-scale or macro level are variations in soil, temperature and rainfall in the whole of Thailand that have already been characterized and mapped, agricultural zones have been demarcated. Detail maps of the country's soils and agricultural zones are accessible from the website of the Department of Land Development (www.ldd.go.th). Variation at the fields and farms is poorly defined. Although such micro level variations could be characterized with a new technology of "precision agriculture", now being promoted as a fertilizer management tool on individual farms in developed countries. Logistic, economic and technical constraints together make it impossible to imagine such precision being applied in resource poor farms of developing countries. Farmers are the only source of this crucial information. Obviously it is not possible to ask every farmer and neither are all farmers equally knowledgeable. Patterns of local variation may be derived from information provided by those farmers who are well informed on local variation in the biophysical environment (Suthi, 1985; Rerkasem et al., 2002), supported by strategic measurements and instrumentation.

Because different crop genotypes may be adapted to different habitats, diversity in the biophysical environment is the primary basis for diversity in local crop genetic resources. However, field fragmentation is generally considered inefficient in the management of large commercial farms. On small farms it would be tolerated and so local crop genetic diversity preserved only if it does not interfere with farmers' management objectives. Local varieties will be maintained only if they are part of sufficiently productive cropping systems that can meet the need of the farm household better than other alternatives. Such diversity of rice-based cropping systems were commonly found in the Chiang Mai Valley in the early 1980's, and each of the condition for a rice variety was termed "agroecological niche" (Rerkasem and Rerkasem, 1984). They have also been found with other crops in other parts of the world, the term "mutiniche" has been suggested for habitat fragmentation which is economically and socially viable (Bellon, 1996).

Diversity in farmers' management and innovation

Farmers' management and innovation affect local genetic resources in two different ways. A farmer may influence local crop genetic system by his/her direct choices over the genetic stock, or through various agronomic practices and care given to the crop. The fate of a local rice variety is determined by the collective choice of individual farmers who may choose or not to choose to grow and perpetuate it. Unlike the pure line varieties from plant breeders, local crop varieties are commonly genetically heterogeneous. Genetic make up of a local variety may be affected by how its seed is propagated from season to season, and whether selection pressure is applied by the farmer when he/she pick the seed for growing in the next season. Different varieties are sometimes deliberately mixed together for various agronomic and other reasons (Dennis, 1987). Genetic shifts may also occur with changes in cultivation practices from land preparation, planting, fertilization, pest management to harvest and seed storage. The diversity of habitats and different ways in which the crop genetic system is manipulated are the condition on which local genetic diversity of a particular crop may be derived.

Rice farmers in Thailand have been practicing selection of their seed stock long before anyone even thought about "participatory plant breeding". Evidence of this may be seen in the 20,000 entries of local rice varieties in the national genebank (Vutiyano, 2000). Some of these would have been results of farmer's selection from existing diverse populations. Others could most probably have arisen from progenies of wild X cultivated rice hybridization that commonly emerged in rice fields throughout the country (Oka, 1988; Chitrakorn, 1995). In the field during harvest time in 2001 we saw again the practice common in the Chiang Mai Valley in the 1980s (Rerkasem and Rerkasem, 1984) in which some farmers selected seed for next season planting from panicles with specific appearances. Many who grow glutinous rice also believe that unless they practice seed selection the eating quality will deteriorate and cooked rice becomes hard. Others believe that changing their seed stock by reintroduction of the same varieties from other areas will "re-invigorate" the variety. It would be useful to know what impact these practices have on diversity in the local rice genetic resources, and what will happen when their function is no longer valued on farm. The use of "certified seed", in which genetic homogeneity is ensured, will certainly limit variation within populations and opportunity for selection by farmers.

In addition to the conscious selection of seed stock, which directly affects genetic make up of varieties, the rice genetic system may also be influenced by cultivation practices. Some of these are in the form of simple variety replacement. Thus irrigation would have replaced deep water and floating rice varieties with those that require better water control. When shifting cultivation is replaced by wetland rice in the highlands, whole sets of upland rice germplasm disappeared. Other changes are less obvious. Improved growing condition for upland rice in rotation with cabbage in the highlands means that preference would be given to those varieties that are able to respond to the better condition with higher yield. Another set of information that would be useful to *in situ* conservation of Thailand's native rice germplasm would include answers to the question how local rice genetic system is affected by "modern" practices in the production system. These included planting method, double cropping, chemical weed control, use of chemical fertilizer, combined harvesting, the use of new rice varieties, from those which are more genetically compatible with local wild rice to transgenic rice. In Vietnam, weedy rice has been reported to have become invasive in the south where rice is direct seeded and not in the north where it is transplanted, and more serious in the summer › autumn crop than in other seasons (Chin et al., 2000). Farmers in Kanchanburi and Nakorn

Nayok reported that wild rice that had existed for a long time in the village swamps had become invasive in the rice field since the arrival of combined harvester and chemical weed control.

Diversity in institutional arrangement

As part of the Green Revolution, habitats for wetland rice in Asia were made uniform by large publicly funded irrigation development projects. These provided support for land leveling, irrigation water and support programs that guaranteed cheap and sometimes free inputs of fertilizers and pesticides as well as guaranteed market and prices. Farmers in the Philippines were persuaded to grow “improved” instead of their own varieties by government supported programs that excluded traditional varieties from various services provided (Basilio and Razon, 2000). The adoption of the Green Revolution rice in Asia, from India to Indonesia, was strongly persuaded with various supports and incentives by the government that sometimes enforced at the point of the gun (Pretty, 1995).

Clearly, government actions do not necessarily always have to lead to losses of niches and diversity. The conventional procedure for centralized rice breeding programs in Thailand is the “official adoption” of local “elite” varieties. Genetically heterogeneous local populations have been genetically homogenized through the “pure line selection” method, i.e. the whole population of a particular variety becomes genetically homogenous as every plant is descended from one single homozygous parent. Thus a local elite from Bangkhla near Bangkok named Khao Dawk Mali, became KDML105, Pingaew became Pingaew 56, Nahng Mon became Nahng Mon 4, Muey Nawng became Muey Nawng 48E and Muey Nawng 62M, and so on. It would be useful for national breeding programmes to re-examine a suggestion made many years ago (Allard and Bradshaw, 1964) that gene diversity in populations may bring about populational buffering to stabilize yield. A recent study in China showed experimentally that genetic heterogeneity in the field can help to overcome the vulnerability of crops to diseases (Zhu et al., 2000).

Local traditions and institutions that may affect usage and conservation of crop genetic resources may vary from ceremonial and ritualistic roles of some crop varieties to customary rules governing usage of common resource including sharing and exchanges of germplasm, to market and trade arrangements. In some areas the management of hired or exchanged labor requires that certain crop management practices such as transplanting and harvesting of different fields is staggered over a length of time. In such areas different varieties that require to be planted and harvested at different times will always be needed (Rerkasem and Rerkasem, 1984). Such needs can vary among ethnic groups and from place to place. The effect of cultural difference is most clearly illustrated by the change of dominance between non-glutinous KDML105 and glutinous but otherwise closely related RD6 rice in the North and Northeastern provinces. KDML105 dominates in all those provinces where non-glutinous rice is staple and where glutinous rice is staple RD6 becomes dominant (Table 4). Where crop genetic resources are treated as common property, and are readily exchanged and shared, many will contribute to its conservation and selection, and so genetic variation. Those heirloom varieties that are jealously guarded within clans and families are likely to be unique. The application of intellectual property laws to new crop varieties is generally expected to provide private incentives for crop genetic improvement. With the intention to encourage conservation, Thailand’s New Plant Variety Protection Act 2542 also provided protection to community’s right to traditional varieties. It remains to be seen if these legislation have the intended effects. Various other forms of institutional arrangements apart from the national government and its formal laws, regulations and development policies, may also influence local crop genetic resources.

Table 4. Choice between glutinous (RD6) and non-glutinous (KDML105 and RD15) of closely related varieties† in some provinces of Thailand.

Province	RD6	RD15	KDML 105	Total KDML† area
		%		*(rai)*
North				
Chiang Rai (G)‡	87.1	10.4	2.5	860,210
Payao (G)	76.9	20.6	2.5	445,846
Lampang (G)	93.8	0.3	5.9	285,198
Lampoon (G)	88.4	1.4	10.2	105,131
Chiang Mai (G)	88.0	1.5	10.4	392,722
Mae Hong Son (NG)	5.4	-	94.6	40,783
Tak (NG)	25.4	2.2	72.4	92,572
Kamphaeng Phet (NG)	-	9.5	90.5	76,767
Sukhothai (NG)	34.4	13.5	52.1	183,238
Phrae (NG)	96.8	2.6	0.5	153,874
Nan (NG)	100.0	-	-	17,009
Uttaradit (NG/G)	45.2	-	54.8	87,084
Phitsanulok (NG)	35.8	-	64.2	145,563
Pichit (NG)	-	-	100.0	50,575
Nakon Sawan (NG)	36.1	-	63.9	185,852
Uthai Thani (NG)	-	-	100.0	14,522
Petchabun (NG)	36.4	-	63.6	320,768
Northeast				
Loei (G)	88.9	-	11.1	131,320
Nongbua Lampoo (G)	91.3	-	8.7	722,913
Udon Thani (G)	92.1	4.2	3.6	1,492,798
Nongkai (G)	90.7	4.0	5.3	1,048,475
Skol Nakorn (G)	90.9	-	9.1	1,272,770
Nakon Panom (G)	69.7	3.5	26.8	669,264
Mookdaharn (G)	95.6	-	4.4	323,626
Yasothorn (NG/G)	44.3	16.7	38.9	970,876
Amnaj Charoen (G/NG)	49.5	2.9	47.6	921,890
Ubon Ratchatani (G)	60.9	2.9	36.1	2,490,683
Srisaket (NG)	10.3	5.4	84.2	2,348,563
Surin (NG)	3.6	13.2	83.2	2,351,466
Burirum (NG)	17.9	9.5	72.6	2,053,461
Mahasarakam (G)	74.6	8.5	16.9	1,534,349
Roi-et (G)	56.5	3.8	39.7	2,168,133
Kalasin (G)	83.3	-	16.7	950,823
Khon Kaen (G)	85.2	1.8	13.0	1,769,046
Chayapoom (G/NG)	45.7	8.7	45.6	900,344
Nakon Rachasima (NG)	20.5	6.4	73.1	2,036,127

† Combined area under nonglutinous KDML 105 and RD15 and glutinous RD6. Both RD 6 and RD 15 are derived from KDML105 by mutation with radiation.
‡ Province where glutinous (G) and non-glutinous (NG) rice is main staple.

The arrival of markets may mean that farmers' choice of varieties will be determined elsewhere as well as locally. The market is not necessarily always an enemy of diversity but may actually help to enhance it. It has been shown that income elasticity of demand for special quality grains may be higher than the income elasticity of demand for the cereal itself (Pingali et al., 1997). For example, an increasing interest in blue corn, waxy Hmong corn or hand milled hill rice in city markets may add an economic incentive for certain groups of farmers to maintain their traditional varieties. Thus special quality rice such as Basmati rice from Pakistan and India, Jasmine rice from Thailand and traditional japonica rice in Korea and Japan are fetching premium prices. Many different kinds of rice, with variously different pericarp pigmentation, can now be seen the rice retail market throughout Thailand. Some hilltribe farmers in Northern Thailand now regularly sell their own hand milled hill rice and with the proceeds buy twice to four times as much rice from the lowland market. In Chiang Mai some farmers find ready market and good prices for special rice that are fed to prized fighting cocks.

Within this broader picture, niche diversity may still be found because of numerous different variations and combinations of the socio-economic conditions of individual farm households. Some poor farmers in the North and Northeastern regions of Thailand find the good eating quality of RD 6 to be a disadvantage in their household economics. They reasoned that because "it tastes so good, we tend to eat too much, so the harvest runs out before the next season crop is ripe". Farmers in some rainfed rice area in Chiang Mai choose to grow traditional tall varieties because they can also sell the straw as mulch for garlic, shallot and onion. Ethnic minority groups have special varieties that are preferred for home consumption. Traditional varieties are also kept for medicinal purpose, as "heirlooms" ("our mother/ grandmother said to keep this"), or even as "pet rice" ("we are not sure why we keep this, but we like it").

DIVERSITY IN THAILAND'S LOCAL RICE GENETIC SYSTEM

How much diversity remains in Thailand's local rice germplasm? Which processes contributed to genetic changes in the past, which of them are likely to continue to do so into the future? With only one fifth the country's rice land planted to traditional local varieties, many of the old varieties have clearly disappeared from farmers' field. However, planted area tells only partial and incomplete story, and similarly number of traditional varieties that are still grown. Most papers on *in situ* conservation refer to the names and types recognized by farmers. Diversity, by definition, is measurable by the statistical term of "variance". In applied genetics, it refers to the variance of "a gene" within a population. Thus the variance may be measured among alternative forms (polymorphism) of a gene (alleles) at individual gene positions on a chromosome (loci), among several loci, among individual plants in a population or among populations (Brown et al., 1990). Diversity may be estimated from variances of morphological or physiological expressions of the gene. With the advent of molecular genetics, we can now measure the variance of actual DNA sequences of a gene or a specific length of DNA (a DNA marker). In addition to quantifying diversity by measuring the variance of genes and DNA markers within and between populations, an understanding of the structure and dynamics of the diversity and their causation is crucial to the management of crop genetic systems. Furthermore, "coancestry" of homologous genes in individuals and populations of local varieties, and the evolutionary forces affecting the whole genome may be learned from estimates of marker diversity (Brown, 1999). Such knowledge would inform decisions on which populations need to be conserved and what conditions are needed to enhance *in situ* conservation in the long run.

The structure of diversity

The *ex situ* collection of rice germplasm at the National Rice Genebank, which began in 1937, holds 24,000 entries. Among these there were 5,900 that did not share the same name (Vutiyano, 2000). Number of named varieties is misleading. Among the 6,000 entries that have so far been characterized by various morphological and some physiological traits (Vutiyano, 2001), varieties with the same name were often clearly different. Some generic names, especially by colour of the husk, e.g. red, white, yellow, and so on, are often given to very different rice from different parts of the country. *Luang On* (soft yellow) was one of the most popular names, it was borne by 32 different entries. Some of the other popular names were *Tong Ma Eng* ("gold that came by itself", 9 entries), *Kao Daeng* (16 entries for "red rice"), *Khao Tahaeng* (19), *Khao Puang* (17), *Luang* (18 entries for yellow), *Luang Thong* (24 entries for "golden yellow"), and *Luang Pratew* (12). A total of 34 populations of rice were collected from Rangsit and Ayuthya with the name *Pingaew.* Apart from obvious morphological (grain shape and size, grain quality) and physiological (some were deep water rice some were regular wetland rice) differences, DNA analysis of 36 SSLP (Simple Sequence Length Polymorphism) markers showed that all except 4 of the populations differed from one another by more than 50% (Vanavichit et al., 2001).

In contrast to "improved" varieties that come out of breeding programs, local varieties carry a great amount of genetic diversity within individual populations. Genetic diversity in both morphological traits and isozymes were observed in one population collected from the lowland and one from the upland of Chiang Mai (Oka, 1988). However, this aspect of diversity existing in local rice germplasm remains to be investigated. Studies of local germplasm often treat each named variety as genetically homogenous (e.g. Chitrakorn, 1995; Pankao, 1996; Chantaraprayoon, 1997). Variation in morphological traits such as the presence of awns, hull and pericarp colour and some physiological ones such as time of heading can be commonly observed in farmers' field. Some of the variation may have resulted from accidental and random mixing of seeds. Some farmers may also deliberately mix seeds from different varieties. Isozyme analyses of "admixtures" showed that some were indeed random mixtures of discreet types, but others exhibited continuous variations that indicated natural heterogeneity (Dennis, 1987). Some variations are recognized as useful by farmers, as long as they do not interfere with or may be useful in crop management or usage. *Bue Chomee* (wild fowl rice), one of the most popular varieties for highland paddy in Northern Thailand contains considerable variation in heading dates, but matures uniformly. Variation in dates of heading is valued for the flexibility provided against gall midge, one of the region's most prevalent insect pest that is most damaging at panicle initiation. A measure of yield stability is provided by those panicles that initiated at different times and so escaping damage. *Bue Chomee* also cooks uniformly. Most of the women farmers, who are usually responsible for cooking, insist that rice that are accidental or random mixtures are not acceptable because they cook badly, as different types would require different length of time to cook. The within variety genetic diversity could be an important component of *in situ* conservation of rice genetic resources. At Chiang Mai University we are investigating within variety diversity of *Bue Chomee* and other popular local varieties such as *Bue Polo* (large grain rice), *Bue Hmong* (Hmong rice, responsive to improved condition in rotation with cabbage and other highly fertilised vegetables) that have arisen from farmers' selection.

The six major biophysical environments listed above may be a good starting place to conceptualize the structure of the genetic system of Thailand's native rice. Adaptation barriers, especially lethal ones, could indicate separation of genepools. An obvious example would be the limited chance of survival in low lying areas of the Central Plains for rice from other environments without flood tolerance and/or "floating ability", ability to keep up with rising flood water by stem elongation. Rice from the Central Plain sets seed poorly, producing largely empty grain, when grown in the North, and similarly when rice from the lowlands is grown in the highlands. Unlike natural species, crop plants not only have to survive a move into a new environment but must also be reasonably productive. Generally upland varieties will survive and produce seed under wetland conditions, and *vice versa*. However, varieties that are equally productive under dryland and wetland conditions are rare, *Sew Maechan* and *Kae Noi* are two known exceptions. Photosensitivity prevents most local populations from being grown in the dry season. Although many would flower in the longer days of April and May, most of them produce only a few panicles and are not sufficiently productive as dry season crop. Ecological, management, technological and other considerations may provide the basis for further differentiation of populations. Populations may also be very different if they had been separated for a very long time. Truly indigenous populations of lowland rainfed rice from the neighbourhood of the two prehistoric sites of earliest records of rice, the Spirit Cave in the North (Gorman, 1969) and Non Nok Tha in the Northeast (Solheim, 1972) might be expected to be very different. A group of glutinous rice from the Northeast has been found with grain shape that was clearly distinct from non-glutinous rice and glutinous rice from other parts of the country (Figure 2).

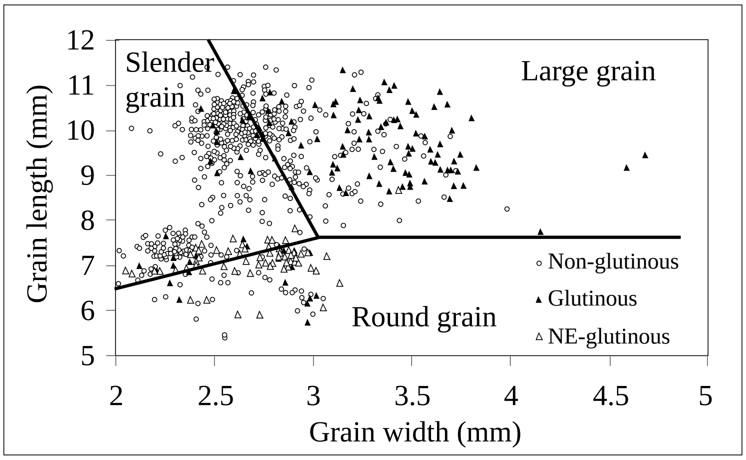

Figure 2. Distribution of grain size (length:width) of a set of glutinous rice germplasm from the Northeast (NE-glutinous) compared with non-glutinous (Non-glutinous) and glutinous (glutinous) rice from the rest of the country. The lines separating grain with different shapes were adapted from Oka (1988).
Source: Plotted with data from OAE (1998)

Genetic changes over time

Local use and management of rice germplasm has influenced local diversity of rice genetic resources in the past in two major ways. The first is by introduction of new genetic materials from elsewhere, and the second is by selection from existing diversity, from within populations as well as between them. Introduction of new germplasm from elsewhere was common even when it was not so easy to travel around the country (Rerkasem and Rerkasem, 1984). Information about promising varieties and seeds were disseminated by those with opportunities to travel such as traders, migrants and those visiting relatives. Rice brought from "home" is still grown by many recent migrants who arrived in Thailand in 1950's from China, Myanmar and Laos. The pace and range of new germplasm introduction has increased with "modern" development and improved communication and transportation in the past 50 years or so.

The establishment of the Rice Department in 1954, later renamed Rice Research Institute, has been instrumental in germplasm exchanges between different regions and introducing really "exotic" germplasm, from outside the country, including those that are products of modern plant breeding even incorporation of genes from wild relatives of rice. Some of these have lost their original official names and been incorporated into the "local germplasm". In Kamphaeng Phet, a very popular "local" variety known as *Cee See* turns out to be an early HYV imported from the Philippines named C4-63 introduced into Thailand in the mid 1960's. The name *Bue Kaset* is often encountered among local Karen rice names (*Bue* is rice in Karen). Close enquiries found that the name refers to many different kinds of rice, including HYVs, that have originated from governmental, non-governmental and foreign aid programmes that were identified with *Kaset*, a local euphemism for modern agriculture.

Examples of contributions from recent introductions into the local germplasm are provided by Supanburi 1 (released 1994) and Pathumtani 1 (released 2000). Supanburi 1, an HYV, is commonly grown in double cropping, irrigated area around Kanchanburi and Ratchaburi, northwest of Bangkok. It's breeder's code is SPR85163-5-1-1-2, and its pedigree is IR25393-57-2-3/RD23//IR27316-96-3-2-2///SPRLR77205-3-2-1-1/SPRLR79134-51-2-2 (Somrith and Chitrakorn, 2001). Supanburi 1 in farmers' field, however, appears to be genetically diverse and very different from the certified Supanburi 1 from the national Rice Research Institute. A "mixing in" with local germplasm, including wild rice, is suspected. This may have happened mechanically with the spread of combined harvesting, or genetically by geneflow through local wild rice (see below). Pathumtani 1, a semi-dwarf, non-photosensitive, aromatic rice, is a potential source of genes from *Oryza nivara*. The parentage of Pathumtanit 1 includes IR50, which had incorporated genes for resistance to grassy stunt virus from the wild rice, O. *nivara* (Chitrakorn, pers. comm.).

Rice is largely self-fertilizing. Even at the 0.03% › 0.1%, natural cross fertilization contributes significantly to geneflow between genotypes (e.g. Brown, 1957; Rea?o and Pham, 1998). A much greater extent of geneflow can be expected to be mediated by the cross-fertilizing wild rice (*Oryza rufipogon*) which is common throughout the country. Numerous observations have been made of "hybrid swarms" between wild and cultivated rice in Thailand (Oka and Chang, 1961; Morishima et al., 1984; Chitrakorn, 1995). Our survey of the Chiang Mai Valley in the early 1980's found that farmers were very much aware of these new forms

(Rerkasem and Rerkasem, 1984). Because of their largely weedy habit, most were avoided when panicles were selected for seed. But plants exhibiting hybrid vigor were sometimes observed (Morishima et al., 1984), they would presumably be progenitors of emerging new local varieties. The process of geneflow through wild rice is therefore likely to have played a crucial role in past evolution of local rice germplasm. This raises two other issues for future *in situ* conservation: (i) the emergence of weedy rice as serious weed and (ii) the possibility of "contamination" of local genepool by genetically modified rice.

Weedy rice, first noted in Malaysia in 1988, the Philippines in 1990 and Vietnam in 1994, is suddenly becoming a serious problem in the rice fields of Asia (Mortimer et al., 2000). In Thailand invasive populations of wild rice have been found in Kanchanaburi, Ratchaburi, Nakorn Nayok and several provinces in the Northeast in 2001 › 2002 (Chanya Maneechote, pers. comm.). The cause of this sudden invasiveness is still to be identified, and will probably vary from place to place. For example, the weedy rice in Malaysia has been shown, by means of DNA fingerprinting, to be very different from wild rice as well as the crop rice it had invaded, (Mortimer et al., 2000). On the other hand, several signs of introgression were exhibited in rice fields in Kanchanaburi, Thailand. Gene flow between species is suggested by the appearance of many domesticated traits (e.g. prolific reproductive capacity, lower dormancy, husk and pericarp colour, grain shape and size, grain quality, panicle type, awnlessness, shattering resistance and photoperiod response) in the wild population and wild traits (awns, stigma colour and exertion, grain type, pericarp colour, shattering, etc.) in the cultivated population. Where weedy rice has resulted from introgression between wild and crop rice, an obvious dilemma has been raised for *in situ* conservation of wild rice population. Heavy infestation can mean complete crop failure (Puckridge et al., 1988; Chin et al., 2000). The problem of weedy rice is a serious threat to rice production so that they have now become targets for eradication (Mortimer et al., 2000). The implication of wild rice eradication on the process of geneflow and diversity in cultivated rice should be carefully considered.

Anyone concerned about "contamination" of local *Oryza* genepool should be reminded that geneflow is an ongoing process that has been going on for a long time. Large scale introduction of "exotic" rice germplasm into rice fields in the country probably began about the same time as the Green Revolution. RD1, Thailand's own first HYV, a progeny of a cross between IR8 and Leuang Thong, was released in 1969 (Somrith and Chitrakorn, 2001). Other HYVs that followed had various foreign germplasm in their parentage, e.g. TN1 (Taiwan), Sigadis (Indonesia), C4-63 (early Philippines HYV), and various IRRI germplasm featuring wild rice in their pedigree. These "foreign" genes that have been incorporated into the local genepool for some 40 years have at least all come from within the species *Oryza sativa*, or its close relatives with the same genus *Orzya*. Introduction of transgeneic rice would mean potential for geneflow from transgenes from others species. An obvious cause for concern would be herbicide resistace in a genetically modified rice that could be incorporated into local wild rice populations.

THE NICHE FOR LOCAL RICE GENETIC DIVERSITY IN THAILAND'S FUTURE CROPPING SYSTEMS

According to Brown (1999) conservation of genetic resources may have any of the following aims, individually or together:

1. Conserving the maximum number of multilocus genotypes and mximum allelic richness;
2. Safeguarding the evolutionary processes that generate new multilocus genotypes; and
3. Improving the population performance and increasing the productivity in a defined range of local environments.

Some have suggested that to conserve local genetic resources it may be necessary to conserve the whole agricultural systems (Qualset et al., 1997). Agricultural systems, however, have always been changing and will continue to change. How then may the above conservation objectives be reached in agricultural systems that must change and evolve to meet the needs and opportunities of those who make a living from growing rice? Conflicts, and possible trade-offs, can occur between the conservation objectives. Indeed, modern plant breeding has done so well by the improvement of population performance and increasing productivity (objective 3). Its very success has led to the increased dominance of the few improved varieties and displacement of local germplasm, and thus threatening objectives 1 and 2 in the first place. There may also be conflicts between the conservation objectives, which may not be those of farmers' or local communities but driven by national needs and aspiration, and farmers' production and livelihood objectives.

Most ideal in conservation are those "win-win" situations in which local people are able to make a decent living while resources are being conserved. Understanding the agrodiversity of local rice genetic systems as presented above is expected enable such win-win situations involving local rice genetic resources to be identified, and the conditions for their success explained so that they may be encouraged in other locations. Furthermore trade-offs between the various sets of objectives, production vs. conservation and local vs. national, may be weighed and addressed.

ACKNOWLEDGEMENTS

The authors' research group on Plant Genetic Resource and Nutrition at Chiang Mai University (CMUPN*lab*), is supported by Thailand Research Fund. On-going work (2002-2005) on *in situ* conservation and management of Thailand's native rice germplasm at the CMUPN*lab* is funded by the Collaborative Crop Research Program of the McKnight Foundation.

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