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The Agroecosystem of Thai Rice: a Review

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ABSTRACT

The production, distribution and consumption of Thai rice is characterized by diversity at many levels, from rice farmers with different access to resource endowment and modern technology, the world of rice eaters who demand different types of rice, to a vast and genetically diverse rice gene pool. This paper examines the complexity that has contributed to shaping the unique development of Thai rice, which should have significant implications for its future. Continuing growth of production and export since the 1960s has given the lie to an erroneous yet common belief that rice farming in Thailand is non-viable as an economic enterprise and that rice farmers are increasingly impoverished. Irrigation and modern rice technology combined with larger farm size, which drove production and export growth, have also enabled many to make a decent living from rice farming. The payout from the government's rice pledging scheme, which went mostly to rich farmers instead of the poor farmers it professed to help, is highlighted to illustrate the need for agricultural policies to be more precisely targeted. Thai rice, exported to some 160 countries and territories, now feeds more people globally than within Thailand. Far from being a simple outflow of surplus, the international trade of Thai rice has contributed to shaping its production in major ways, as exemplified by the case of parboiled rice, which is almost unknown in Thailand, yet accounts for one third of the country's rice export. With the aid of machinery powered by fossil energy, modern rice technology and chemical inputs, a farm laborer today produces 12 times as much rice as when rice farming relied solely on human and animal power. In addition to labor cost savings, mechanization has also increased the efficiency of rice production with timely completion of crop management operations, increased the value of the harvest with improved grain quality and brought economies of scale by increasing the farm size individual farmers can manage. In common with other rice growing countries, Thailand has benefited from the genetic improvement embodied in modern, high-yielding rice varieties, but only when deployed together with traits from the Thai rice germplasm to satisfy stringent local requirements. The primary gene pool of Thai rice includes not only cultivated rice (Oryza sativa), but also common wild rice (O. rufipogon). Emergence of weedy rice (O. sativa f. spontanea), a hybrid progeny of the cultivated and wild species, as a serious weed in rice fields serves as a reminder that introduction of novel technology and genes, such as

genetically-modified rice and herbicide-resistant rice must not be undertaken without critical assessment of their possible adverse impact on the gene pool. Clear understanding of the complex agroecosystem of Thai rice is crucial for the implementation of agricultural policies and investment in research and development aiming to improve production efficiency and livelihoods of farmers in a sustainable manner. Further productivity growth of Thai rice is achievable through research and development, but only when opportunities and problems in rice production are uncoupled from problems of the poor.

Keywords: Agroecology, Agrodiversity, Agroecosystem

INTRODUCTION

The term "agroecology" was first used in a scientific publication in 1928, but the idea it embodies has changed from its original usage, when it dealt mainly with the application of ecological principals to agriculture, i.e. the cycling of energy and nutrients and the food chains, to become much broader in focus, especially since the 1980s (Wezel et al., 2006). Defined as an "integrative study of the ecology of the entire food systems, encompassing ecological, economic and social dimensions, or more simply the ecology of food systems" (Francis et al., 2003), agroecology as a discipline has since moved beyond the field and landscape of the ecosystem involved in agricultural production, towards a broader focus of the global network of food production, distribution and consumption (Gliessman, 2007). The term "agrodiversity" entered the literature in the 1990s, and is defined as "the dynamic variation in cropping systems, output and management practices that occur within and between agroecosystems (Brookfield, 2002). This has arisen from bio-physical differences, and from the many and changing ways in which farmers manage diverse genetic resources and natural variability, and organize their management in dynamic social and economic contexts" (Brookfield, 2001). Agroecosystem analysis (AEA) was developed as a procedure for understanding complexity of agriculture and assessment of a set of properties, namely productivity, stability, sustainability and equitability, through interdisciplinary interactions, and refined with participation of universities in Southeast Asia in the first half of the 1980s (Conway, 1985). The first AEA, conducted in the Chiang Mai Valley in 1979 by a team of natural and social scientists from Chiang Mai University and Imperial College of the United Kingdom, was an attempt to analyse the complexity of agriculture across 160,000 ha of rice growing area, with highly diverse cropping systems (Gypmantasiri et al., 1980). In addition to the set of key questions for future research and development that was the specific aim of the analysis, workshops involving extensive field visits, exchanges and in-depth discussions with farmers contributed to a perspective of agriculture in which farming is considered in its societal and ecological context. These are the views through which Thai rice will be examined in this paper.

THAI RICE FEEDING THE WORLD

The export of rice in significant volume from the area currently within the Kingdom of Thailand started with improved transportation following relocation of the seat of power from Sukhothai to Ayuthya on the Chao Phrya River in the mid-1300s, and took off in the mid-1600s with Dutch and other foreign traders plying southeast Asia to feed European colonies, to be followed by the rise of trade with China in the early-1700s (Suebwatana and Pruetnarakorn, 1988). Rice export was greatly facilitated with access to larger ocean going vessels when the capital was moved closer to the river mouth at Bangkok in the late-1700s. By the early-1900s, Thailand was exporting more than one million tons of milled rice annually (Sanitwongse, 1927). After a period of stagnation at about one million tons per year for half a century, the export volume grew by 0.192 million tons per year from 1975 to 1996 and accelerated to 0.282 million tons per year from 1997 to 2011 (Figure 1). By 2011, Thai rice was feeding more people globally than domestically, with milled rice export of 11 million tons outstripping domestic consumption of 9 million tons (OAE, 2013). The precipitous crash of Thai rice export, to less than 7 million tons a year in 2012 and 2013, is a serious aberration with profound effects. However, the adverse impact of this on farmers, the system of rice production and trade, the local and national economy and the global rice market awaits a rigorous and critical analysis, which is outside the scope of this review.

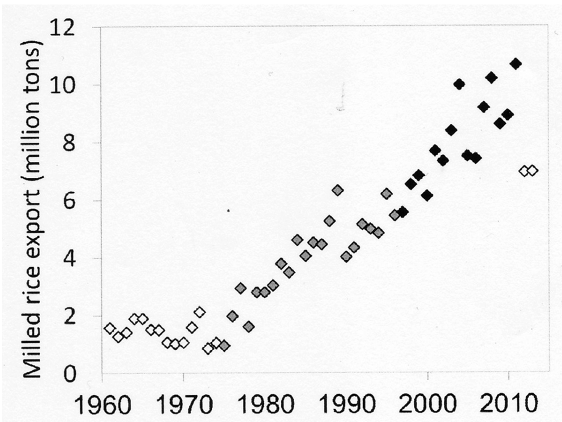

Figure 1. Milled rice export from Thailand between 1961 and 2013 (average rate of growth, million tons per year: ◇ no growth; ◆ 0.192; ◆ 0.282). Source: Drawn from data in FAOSTAT 2012.

By the first decade of the new millennium, Thai rice was exported to more than 160 countries and territories (TREA, 2014). Prices quoted for rice from different exporting countries (FAO, 2014) clearly show that Thai rice occupies the high end of the global rice market. This rice export is not simply a one-way flow of surplus; demand from importing countries has also shaped the production of rice in this country in major ways. A decline in per capita rice consumption combined with a lower rate of population growth has resulted in a slowing down of growth in domestic demand for rice in Thailand (Isvilanonda, 2006). However, strong global demand for rice (Figure 2) has stimulated growth in Thai rice production for more than half a century, reaching the rate of 0.732 million tons per year from 1987 to 2012, doubling the rate from 1961 to 1986 (Figure 3). When traditional rice eaters become richer, they consume less rice as their diet diversifies to include more expensive and nutritionally richer foods (Ito et al., 1989). Global demand for Thai rice has continued to grow in Asia and Africa, which together accounted for 80% of the 3.1 million ton increase in milled rice exported from Thailand between 2001 and 2011 (Figure 4).

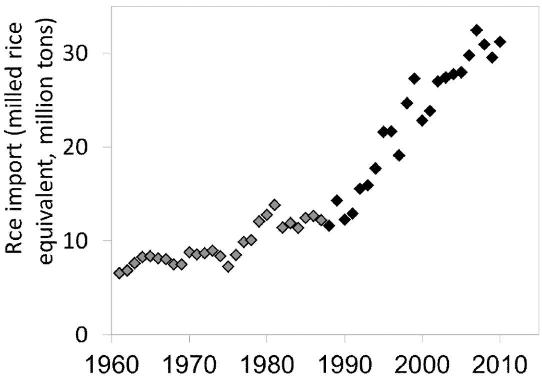

Figure 2. Total global rice import from 1961 to 2010, (average rate of growth, million tons per year: ◆ 0.237; ◆ 0.949). Source: Drawn from data in FAOSTAT 2012.

In rice-eating Asia, demand from the growing population has outstripped supply in major rice producing countries such as Bangladesh, Indonesia, Malaysia and the Philippines. An even more rapidly growing demand for Thai rice comes from Africa, where people who traditionally depend on root crops and grains, such as wheat, maize, sorghum and millet as their staple food, are increasingly eating more rice. In Nigeria, one of the top importers of Thai rice, for example, per capita rice consumption has increased ten-fold from the 1960s to 2000s (Erhabor and Ojogho 2011; Wailes and Chavez. 2012). In Sub-Saharan Africa, demand for rice grew by 4.6% per year between 2000 and 2010, nearly twice the rate of population growth over the same period (Rosen et al., 2012).

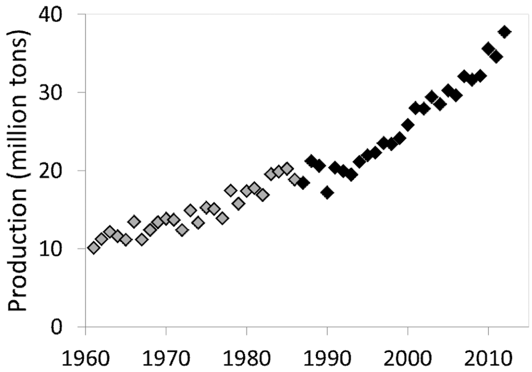

Figure 3. Thailand's paddy (rough rice) production from 1961 to 2012, (average rate of growth, million tons per year: ◆ 0.365; ◆ 0.732). Source: Drawn from data in FAOSTAT 2013.

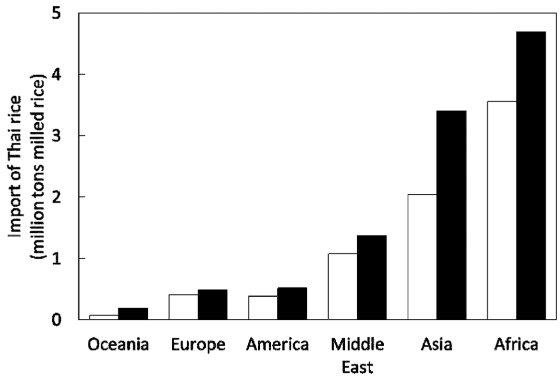

Figure 4. Thai rice import by region in 2001 (□) and 2011 (■). Source: Drawn from data in TREA, 2014.

The world's rice eaters form a diverse group of people who prefer many different types of rice, which determine the types of rice grown by farmers. The 9-10 million tons of rice used domestically in Thailand each year consists of the aromatic jasmine or Hom Mali rice (10-15%), ordinary white rice (60%) and glutinous rice (20-25%). The effect of market demand on the type of rice farmers choose to grow can be seen in the proportion of glutinous to Hom Mali rice grown in the North and Northeast, which fluctuates with their relative prices. Thai rice export began to differentiate by prices and markets towards the end of the 1980s – into ordinary white rice, the premium priced Hom Mali rice for the high-end market, and parboiled rice for Africa and the Middle East (Figure 5a). Market segmentation (Figure 5b) and price differentiation (Figure 6) of Thai rice export are not unlike those for manufactured goods. Quality control for Thai rice begins at the farm, by the price differentials imposed by rice buyers who are highly skilled in determining quality, including an ability to determine the strength of the typical 'jasmine-like' aroma in Hom Mali rice (Leesawatwong et al., 2003; Prom-u-thai, 2010). Incidentally, although the name Hom Mali translates as "fragrant jasmine", the main aromatic compound 2-acetyl-1-pyrroline (2-AP) is common in pandan (*Pandanus* spp.), an Asian culinary leaf, and other flowers (Wongpornchai et al., 2003), but has not been detected in the jasmine flower (*Jasminum* spp.). Parboiled rice, which accounted for one third of the export volume in 2011, is practically unknown in Thailand, except among those involved in its production and trade.

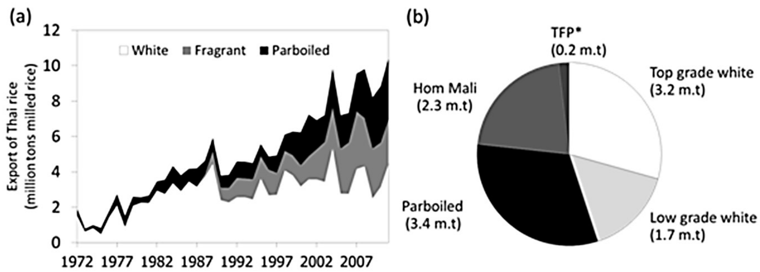

Figure 5. Thai rice export differentiation trend from 1972 to 2011 (a); and by rice of different grades in 2011 (b). (*TFP = Thai Fragrant Pathumthani, priced 10-20% lower than Hom Mali). Source: Drawn from data in TREA, 2014.

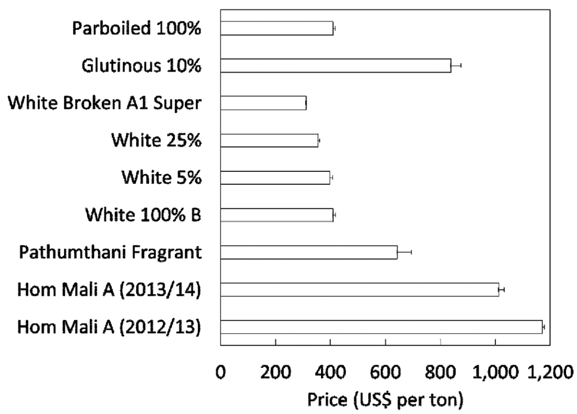

Figure 6. Example of export price quotes for Thai rice, by grades and types (mean of 4 weeks from 19 March 2014 to 9 April 2014, with standard deviation bars). Source: Drawn with data from TREA, 2014.

Parboiled rice or *Khao Nueng* (also refers to sticky or glutinous rice in the northern Thai dialect) is ordinary, non-glutinous rice that is cooked by steam in the husk before milling. This is an ancient method in which wet harvested rice is prevented from spoilage by germination and moulds. Thanks to pioneering developments by third and fourth generation millers, some of whom were educated in the US in the 1970s, parboiled rice mills and export trade have become greatly modernized (Siamwalla and Na Ranong, 1990). From a small amount in the early-1970s, Thailand's parboiled rice export (assumed to equal production, as little is used domestically) grew to 3.4 million ton in 2011, a 13-fold increase (Figure 7). Growth in the parboiled rice industry coincided with Thailand's adoption of modern rice technology dating from the release of RD1, the first modern, high-yielding Thai rice variety in 1969 (BBRD, 2014). Following relatively modest early growth, production and export of Thai parboiled rice took off in the mid 1990s after the release of modern, high-yielding varieties with grain quality especially well-suited for parboiling, such as Chai Nat 1 in 1993 and Suphan Buri 1 in 1994.

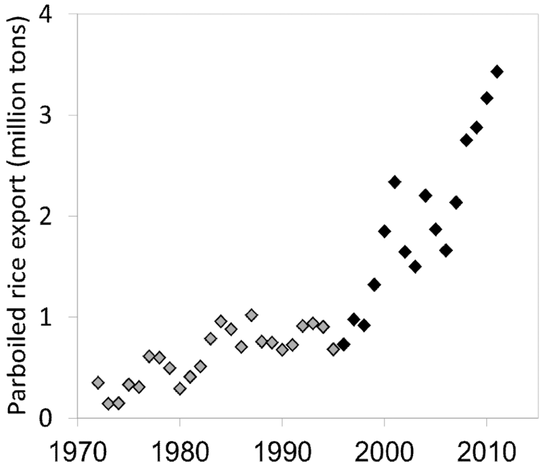

Figure 7. Thailand's parboiled rice export from 1971 to 2011, (average rate of growth, million tons per year: ◆ 0.029; ◆ 0.152). Source: Drawn from data in TREA, 2014.

Parboiled rice is traditionally produced and consumed in the Indian sub-continent; importing countries with rapidly growing demand are in Africa and the Middle East (Garibaldi, 1984). Production and export of parboiled rice has enabled Thailand to capture a much larger share of the global rice market than it would otherwise have done with only ordinary white rice and the premium priced Thai Hom Mali. Without parboiled rice, Thailand's 30% share of the global rice market in 2011 (OAE, 2013) would have shrunk by one third. In addition to its impact in stimulating production, the export growth of parboiled rice has also added value to the rice crop by improving milling quality. Steaming rice in the husk before milling fuses together the starch grain; this strengthens the rice grain and makes it more resistant to milling breakage (Matz, 1991). Milling one ton of paddy rice that has been parboiled produces 580 kg of full grain rice (called 'head rice' in industry and trade) and 70 kg sub-standard broken rice, whereas one ton of raw, un-parboiled paddy produces only 395 kg of head rice and 185 kg broken rice (Siamwalla and Na Ranong, 1990). With about the same price for white (raw, un-parboiled) and parboiled rice, parboiling increases the value of each ton of paddy by about 20%. While the parboiled rice mills realize this particular economic gain, the success of Thai parboiled rice in the world market has also benefited some rice farmers. The next section examines diversity within the Thai rice farming system, which affects how rice farmers have or have not benefitted from modern rice technology and the success of Thai rice in the world market.

WHO ARE THE THAI RICE FARMERS?

An inter-census survey in 2008 found 3.911 million households in Thailand engaging in rice farming, with vastly different scales of operation (Table 1). The very small (averaging 0.6 ha) and small (1.1 ha) operations together make up more than one million rice farms, which accounted for one third of the total number of farms, but less than 10% of the rice land. Medium size farms (averaging 2.9 ha) accounted for 57% of the farms and 58% of the land. The large (8.6 ha) and very large (16.8 ha) operations together make up only one tenth of the rice farms, but occupy almost one third of rice land. Along with other rice growing countries of Asia, Thailand has benefitted from modern rice technology, which includes the deployment of modern, high-yielding rice varieties (David and Otsuka, 1994; Kaosa-ard and Rerkasem, 2000). However, in Thailand the economic benefits have gone largely to those blessed with irrigation, which provides optimum water control during the wet season and reliable water supply during the dry season. Irrigation enables the rice plants to realize their maximum yield potential and farmers to minimise the risk involved in the expense of costly inputs, especially those that are essential for high yield, like fertilizers. Carbon dating of materials in old water diversion structures in water resource rich Chiang Mai Valley indicated that development of irrigation systems for rice culture predated King Mengrai (1238-1317) (Sektheera and Thodey, 1975). Modern public investment in irrigation development in the country began before the implementation of the First National Social and Economic Development Plan (1961-1966), but has subsequently been concentrated largely in the Central region (Figure 8).

Table 1. Distribution of Thailand's rice farms by number of farms and farm size in 2008.

Farm size (1 rai = 0.16 ha)	**Number**		**Area**		**Average size**	
	million	**%**	**m. ha**	**%**	**(rai)**	**(ha)**
Very small (<6 rai)	0.674	17.2	0.426	3.8	3.9	0.6
Small (6-9 rai)	0.587	15.0	0.670	6.0	7.1	1.1
Medium (10-39 rai)	2.243	57.3	6.482	58.0	18.1	2.9
Large (40-140 rai)	0.394	10.1	3.384	30.3	53.6	8.6
Very large (>140 rai)	0.013	0.3	0.217	1.9	101.8	16.3
Overall	3.911		11.179		17.9	2.9

Source: NSO, 2010.

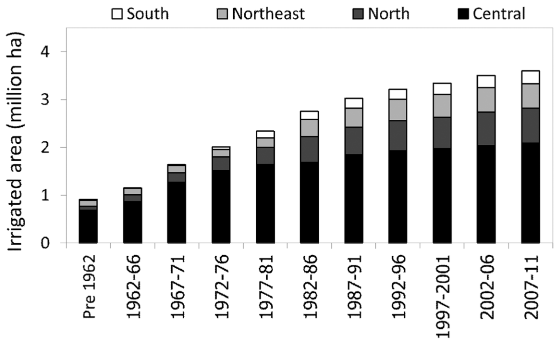

Figure 8. Cumulative area of irrigated land in different rice growing regions of Thailand. Source: Drawn from Pongratananukul and Sirikanchanarak (no date).

Development of irrigation systems in Thailand has historically been associated with rice production, and originally with water control for the wet season crop as the primary aim. *Na Pee*, as the wet season crop is designated in production databases, is planted mainly from May to the middle of August and harvested in November (OAE, 2013). Local (also called traditional) Thai rice varieties are grown only in the wet season, their flowering is controlled by daylength in such a way that flowering and grain development match water availability from the monsoon rains. The advent of modern rice varieties enables rice to be grown as *Na Prang* (off-season crop) in the dry season as well. Thai rice is now sometimes grown continuously, with one harvest immediately followed by the next crop, with total disregard for the season. Thus, irrigation has more than doubled or tripled productivity of the rice land, as multiple cropping is combined with higher yield from each crop. Unfortunately, the benefit has reached fewer than one in five of the country's nearly 4 million rice-farming households, with dry season rice area distributed mainly in the Plain of the Chao Phrya, in provinces stretching from the Lower North to the Central region (Figure 9).

For more than three million of Thailand's rice farming households, rice is grown as a rainfed crop with yield averaging 2.26 tons/ha, only 53% of dry season yield (Table 2). This yield of Thailand's rainfed rice was only 56% of the national yield of Myanmar, 60% of Lao PDR and 82% of Cambodia for the same period (calculated from data in FAOSTAT, 2013). From this extremely low yield per area, rice farming simply does not generate sufficient household income for those with even medium size operations, which produces 6.6 tons of rice per year from a holding size of 2.9 ha, and only 1.4 tons per year from each of the very small holding farms of 0.6 ha. Some rice farmers and their families no doubt make up some of the country's poor, who still numbered more than five million in 2011, accounting for 13.2% of the population (World Bank, 2011). However, national statistics that describe as "farming households" those that derive more than 60-80% of their cash income from non-farming activities (Table 3) are misleading and have inevitably led to flawed and misdirected agricultural policies.

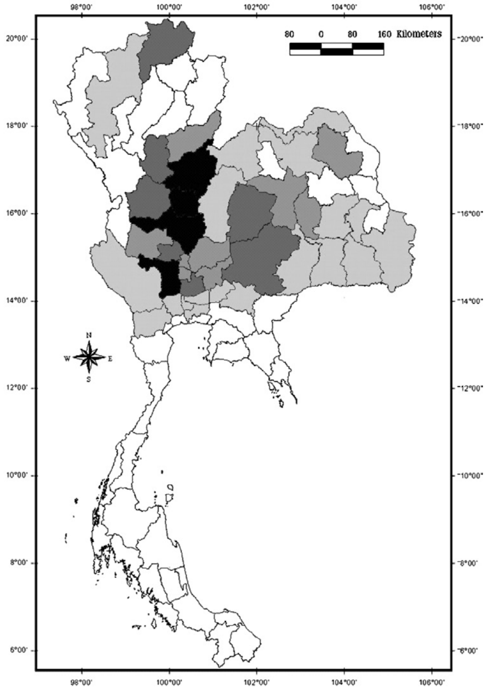

Figure 9. Distribution of dry season rice crop area in Thailand in 2011by province (☐ < 0.1; ■ 1-2; ■ 3-4; ■ 5-7; ■ > 1.0 million rai) (1 rai = 0.16 ha). Source: Drawn from OAE, 2012.

Table 2. Rice farming households, crop area, production and yield of rice in Thailand for 2011/12 growing season by different water regimes and cropping seasons.

Cropping season	Water regime	Households† Number	Area (m. ha)	%	Production (m. tons)	%	Yield (t/ha)
Wet season	Rainfed	No data	7.838	58.8	17.740	46.6	2.263
	Irrigated	No data	2.610	19.6	8.130	21.3	3.115
	Total	3.753	10.448	78.4	25.870	67.9	2.476
Dry season	Irrigated	0.749	2.885	21.6	12.220	32.1	4.236
Total	Irrigated	No data	5.494	41.2	20.350	53.4	3.704
Country total			13.333		38.090		2.857

Note:†As some farmers who grow dry season rice do not grow wet season rice, the number of households growing wet season crop and those growing dry season crop do not add up to the total number of rice farming households for the whole cropping year. Source: Modified from OAE, 2013.

Table 3. Farmer's income in Thailand by region.

	Thailand[1]	North[2]	Northeast[2]	Central[2]	South[2]
	THB per year				
Cash income	227,319	241,865	183,893	404,431	269,768
From farming	136,319	161,745	76,505	269,663	184,565
Off-farm	91,000	80,120	107,388	134,768	85,203
Net cash income					
From farming	57,692	65,609	30,917	91,152	102,632
% from farming	38.8	45.0	22.4	40.4	54.6

Note: [1]Average growing season 2008/9 to 2011/12 [2]Growing season 2011/12. Source: OAE 2013.

Government policies, with laudable aim to help the poor, are doomed to fail and public funds wasted, if they neglect to distinguish between rice farms that are economically viable and those that are not. With financial benefit that increases with the size of production, those with larger farms have benefitted proportionately more from the government's rice-pledging scheme than those with smaller farms, while the benefit to those who grow rice twice a year simply doubles that to those who can grow only one crop per year. From very small to medium size farms (according to Table 1), the rice produced as a rainfed crop was worth on average THB 21,459 to 98,126 per farm per year at the government subsidized price of THB 15,000 per ton, with many receiving even less when some rice is kept for home consumption. In contrast, at the government's pledging price, the production from two irrigated crops per year was worth almost one million Thai baht for each of the large farms, and almost two million Thai baht for very large farms. In an early period of the rice-pledging scheme, an average of THB 405,937 was paid out to each of the 0.269 million larger farms, while the average receipt of 0.345 million smaller farms was only THB 94,579 each (Poapongsakorn and Siamwalla, 2012).

The first months of 2014 were a time of great disturbances for Thai rice. The government, having already spent THB 500 billion of public funds, still owed some THB 110 billion to more than one million farmers for their rice, (see Bangkok Business News, 11 January 2014; The Nation, 14 February, 2014; Daily News, 22 February 2014), while the rice price in the open market plummeted, driven down by the government's rush to unload its stockpile built up since the dry season 2012 harvest (see Bloomberg, 12 February 2014). Compared with rice of similar grade from other countries, the prices of Thai ordinary white and parboiled rice for January and February 2014 dropped precipitously from the same period in 2013, with similar trends for the average annual prices from 2009 to 2013 (Table 4).

Table 4. Changes in export prices of Thai rice and rice from other countries with comparable grades (USD per ton, f.o.b.).

Rice type, by origin and grade	Jan-Feb price		% Change	Annual price		% Change
	2013	2014		2009	2013	
Thai White 100%B	614	461	-24.92	587	534	-9.0
Thai Parboiled 100%	603	463	-23.22	619	530	-14.4
Thai 5%	597	455	-23.79	555	518	-6.7
US Long Grain #2, 4%	620	600	-3.23	545	628	15.2
Thai Hom Mali Grade A	1182	1152	-2.54	954	1180	23.7
Pakistan Basmati	1359	1372	0.96	937	1372	46.4

Source: Data from FAO, 2014.

The enormous capacity of the Thai rice agroecosystem to take advantage of new technology and market opportunities has been highlighted by continuing growth in production and export. However, when all of the farmers are paid the money owed for their pledged rice, and the rice stockpiles are gone from the government's warehouses, there may be sufficient resilience to regain this former strength and adaptability, but only if key components and processes in the agroecosystem have not been permanently damaged.

THAI RICE FARMING IN THE 21ST CENTURY

While nostalgic urban Thais bemoan the disappearance of buffaloes and the tradition of labor exchange from the country's rice fields, the substantive transformation that has taken place in rice farming in Thailand is evident in the 12-fold increase in rice yield per unit of labor (Rerkasem, 2014). The replacement of animal and human power with fossil energy driven machines and increased use of chemical fertilizers, herbicides and pesticides accompanied this increase in labor productivity, while yield per unit land increased by only 81% over the same period (calculated from data in FAOSTAT, 2013). In addition to the savings in labor costs, mechanization also enables timely completion of various farming operations, from land preparation to harvest, as well as providing economies of scale by increasing the farm size individual farmers can manage. One man with a buffalo can plough only 0.16 ha (1 rai) per day, since buffaloes only work a 5-hour day. By contrast, in one day a man can work 3-6 times as much land with a 7-12 horsepower tractor, and 9-12 times as much with a 35 horsepower tractor. While rice is still planted by broadcasting or transplanting, machines play a much bigger role than even a couple of decades ago; machines modified from motorized chemical sprayers broadcast much more rapidly and efficiently, while machine transplanting is becoming common.

Mechanization has greatly improved efficiency in the rice harvest, once an extremely labor-intensive part of rice farming. Manual rice harvest involves cutting the plants, gathering and binding them into sheaves, carrying them to the threshing floor, threshing to separate the grain from straw and cleaning to remove chaff and other bits of rubbish from the grain. With a combined harvester, which combines the reaping, threshing and grain cleaning action in one pass, one man can harvest one hectare in about three hours. In contrast, it would take 600 people to accomplish the same (calculated from data in Punsema and Boonkird, 2013). Machine harvest also adds value to the rice by improving grain quality and shortens the growing season. Labor shortages during the rice harvest used to have a serious detrimental effect on rice quality and value. While the ripe crop stood waiting for the harvesting crew, the grain became over dried and brittle, producing mostly sub-standard broken rice when milled. Machine harvesting allows rice to be harvested at a relatively high moisture content of 20-30%; prices paid to farmers are adjusted according to water content. The wet paddy is dried to 15% moisture content by driers that use energy from burning the rice husk (Thepent and Chamsing, 2009), or sent to parboiled rice mills.

In addition to mechanization, Thai rice farming has also been changed by outsourcing of the various crop management activities, from land preparation, planting, application of fertilizer and pesticides, to harvesting. Transplanting by machines is operated by contractors, who may also provide rice seed and seedlings, for a fee charged per area. In some areas, outsourcing may be restricted to certain operations, e.g. land preparation or harvesting, while in other areas all activities are contracted out, with the mobile phone being the only essential “farm implement”. Some larger farms that have chosen to invest in machines and their maintenance may also operate as contractors to other farmers.

As of 2011, Thailand’s economic status has been upgraded from a low-middle income to a high-middle income country (World Bank, 2011). Along with changes in the way rice is produced, the social and economic transformation over the past half-century has wrought many other major changes in rural life. From a population that was four-fifths rural in the early-1960s, the majority of Thais will be living in urban areas by the late-2010s (Rerkasem, 2014). Those who have left the farm were predominantly in the 15-24 age group, most of whom stayed on in school and some going on to higher education. For example, between 1989 and 1999 the number of people aged 15-24 in Thailand who were farm workers declined from 5.8 to 2.5 million, but the number of those who stayed in education increased from 0.7 to 2.4 million, while those who were in non-farm employment increased from 1.1 to 1.6 million (Siamwalla, 2003).

Rice farming, like any agricultural production, involves the management of an ecosystem for an expected output, the rice grain in this case. Application of agricultural science has enabled increasingly larger output to be extracted from limited resources, i.e. with higher yield of rice per land area and unit of labor. However, sustainability of the system is threatened when some key component or process is neglected by technology developed from increasingly specialized scientific disciplines with ever narrowing focus, on individual nutrients, pests or genes. Another source of perturbation comes from the failure to connect with social and economic factors that are an integral part of the agroecosystem. Thus, rice farmers were not the only casualties of the failure of the Thai government to pay for their pledged rice. The adverse effects on the local and national economy of this costly policy on farming contractors, suppliers of inputs, local rice traders and mills await definitive accounting. Emergence of unexpected biological threats are exemplified by outbreaks of new pests of the world's rice fields, like the brown plant hopper (Kenmore, 1980; Conway, 1999) and golden apple snails (Naylor, 1996), and invasive weedy rice in Thailand (Maneechote et al., 2004). Genetic diversity of the local rice germplasm is an innate strength that has played an important role in development of Thai rice in the past, but its value for future growth and sustainability of Thai rice is not immutable.

GENETIC DIVERISTY IN THE THAI RICE GENE POOL

Thailand lies partly within the area considered the center of diversity and origin of rice (Harlan, 1992). Studies in the 1950s and 1960s found genetic diversity of cultivated rice to be most prevalent in Thailand's rice fields, along with those in Assam in India, Bangladesh, Myanmar, Laos and Yunnan in China (Oka, 1988). Commercial success of Thai rice, however, has led to replacement of local varieties by commercial varieties. By the wet season of 1996, the last time a detailed survey was conducted, local rice varieties were planted in less than 20% of the country's rice land (Rerkasem and Rerkasem, 2002). Nevertheless, local varieties are an important resource for rice growing areas in the country that are beyond the reach of commercial varieties for ecological and social reasons (Rerkasem, 2008). Locally adapted varieties may sometimes be tolerant to biotic stresses, such as insect pests (Oupkaew et al., 2011) and diseases (Naruebal, 2009), or abiotic stresses, such as soil acidity (Phattarakul, 2008) and flooding (Sommut, 2003). Rice grown in the highlands, with the highly diverse biophysical environment of the mountain landscape and variations in the microclimate and soil, as well as traditions and customs of people belonging to different ethnic groups, is invariably of local varieties, with unique sets of germplasm maintained by each of the minority groups (Sirabanchongkran et al., 2004; Unthong 2006; Rerkasem, 2008;).

Local crop varieties or landraces are recognized by their unique morphology and well-established local names, with genetic variation within as well as between populations (Brown 1978; Harlan 1992). Genetic diversity of Thai rice, quantifiable by both phenotype and genotype, is much greater than would have been inferred by area planted to local varieties or the number of named varieties. In an entirely non-centralized naming system of local rice varieties, the same names are often given to rice with completely different genotypes, while the same genotypes may be differently named at different times or places. Molecular diversity studies provide an understanding into the structure of genetic diversity in local rice varieties. Genetic variation among individuals that complete their life cycle together in the same field indicates the evolutionary flexibility essential for local adaptation, while natural and human-mediated selection may be reflected in genetic differentiation among seed lots of the same variety from different farmers and villages. This has been demonstrated in the case of Bue

Chomee, a wetland rice variety popular in Karen villages in the highlands west of Chiang Mai (Pusadee et al., 2009), and Muey Nawng, a gall midge resistant variety of the foothill valleys of northern Thailand (Pusadee et al. 2013).

Functional diversity in local Thai rice germplasm covers those characteristics that are important to eating and other usages, as well as the growing of rice. The presence of individuals with non-waxy endosperm among those with waxy endosperm has enabled gall midge resistant non-glutinous rice to be developed to meet the preference of ethnic minority groups in the highlands (Oupkaew et al., 2011; Chaksan, 2013; Punyakarn, 2013). Local Thai rice varieties have been identified with special grain qualities, including exceptionally high levels of iron and zinc (Pintasen et al., 2007; Saenchai et al., 2012; Jaksomsak, 2014), the micronutrients often deficient among rice eaters (Hotz and Brown, 2004; Welch and Graham, 2004); novel biologically active compounds (e.g., Boonsit et al., 2010; Sangkitikomol et al., 2010; Yodmanee et al., 2011; Saenjum et al., 2012); and the ability to keep toxic cadmium out of the grain (Sriprachote et al., 2012), which may be utilized in medicine or industry, as well as nutritionally beneficial to rice eaters.

Molecular diversity studies have suggested that Thailand was part of the area where indica rice, the type of rice grown in tropical Asia, was first domesticated from local wild rice (Londo et al., 2006). The common wild rice (*Oryza rufipogon*) is still very much a part of the rice landscape in central and northeastern Thailand today.

The emergence of weedy rice (*Oryza sativa* f. *spontanea*) as a noxious weed of rice fields in Thailand is a reminder of another important element of the agrodiversity of Thai rice. Genetic analyses have shown that weedy rice in Thailand is the hybrid progeny of the cultivated and wild species (Sinthukiew et al., 2005; Niruntrayakul et al., 2009; Pusadee et al., 2013; Wongtamee, 2013). First observed in a farmer's field in Kanchana Buri in 2001 (Maneechote et al., 2004), weedy rice now adversely affects rice yield and quality across Thailand, from the irrigated, continuous rice area growing, modern varieties in the Plain of the Chao Phraya in the Lower North and Central regions, to the premium Thai Hom Mali rice area in the Northeast (Maneechote, 2009; Wongtamee, 2013). "Hybrid swarms" of plants with combined characteristics of wild and cultivated rice were observed in rice fields with neighboring natural wild rice populations (Oka et al., 1961), and would have undoubtedly given rise to numerous local Thai rice varieties. Biological and ecological advantages conferred by development of modern rice farming, such as when transplanting was replaced by direct seeding and the ability to flower and set seed all year round in modern rice varieties, have enabled the wild and cultivated rice hybrids to become invasive in rice fields. While the evidence is mounting on clear global economic and social benefits from biotechnology and genetically modified crops (James, 2011), introduction of genetically modified rice or novel genetic traits such as resistance to herbicides should never be undertaken without considering possible adverse effects on the primary gene pool of rice.

CONCLUSION

The agroecosystem of Thai rice is diverse at many levels. These offer opportunities for future improvement and growth, as well as limitations. Agricultural policies and investment in research and development aiming to improve production efficiency and livelihoods of rice farmers in a sustainable manner need to be based on in-depth understanding of this diversity and complexity. Most importantly, problems of rice farming must be decoupled from problems of the poor; and a clear distinction must be made between households that depend largely on rice farming for their livelihoods and those that derive only a small fraction their income from farming.

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