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The rice-plant: diversity and intensification

Rice is the staple food of almost half the population of the world, second only to wheat in its importance. The annual world rice harvest in 1981–2 came to over 400 million tonnes, from a cultivated area of about 145 million hectares (Swaminathan 1984: 65), while in 1978–9 world production of wheat was 450 million tonnes from 230 hectares (Fischer 1981: 249). Over the centuries rice has become an increasingly popular food not only in Asia but throughout the world, replacing tubers, millets and other food grains as the staple food in island Southeast Asia and parts of Europe, Africa and Latin America; it has become an increasingly important export crop in the USA and Australia. But the bulk of the world's rice crop is produced in monsoon Asia, the zone where it was first domesticated: 90% in monsoon Asia as a whole, and 64% in East and Southeast Asia alone (Swaminathan 1984: 65).[1] Despite a recent preference for bread and other wheat products among the wealthier classes, rice is by far the most widely consumed and cultivated crop in the Far East.[2]

This chapter will describe briefly the historical advance of rice cultivation through East and Southeast Asia, showing how the natural characteristics of the plant, its flexibility and enormous potential for breeding varieties suitable to almost any ecological or economic circumstance, permitted the increasingly intensive use of land and encouraged an ever greater number of both subsistence and commercial farmers to rely on it as their staple food.

The origins of Asian rice

The origins of domesticated Asian rice are still undetermined, but the distribution of wild rices (figure 1.1) suggests a centre, or centres, of

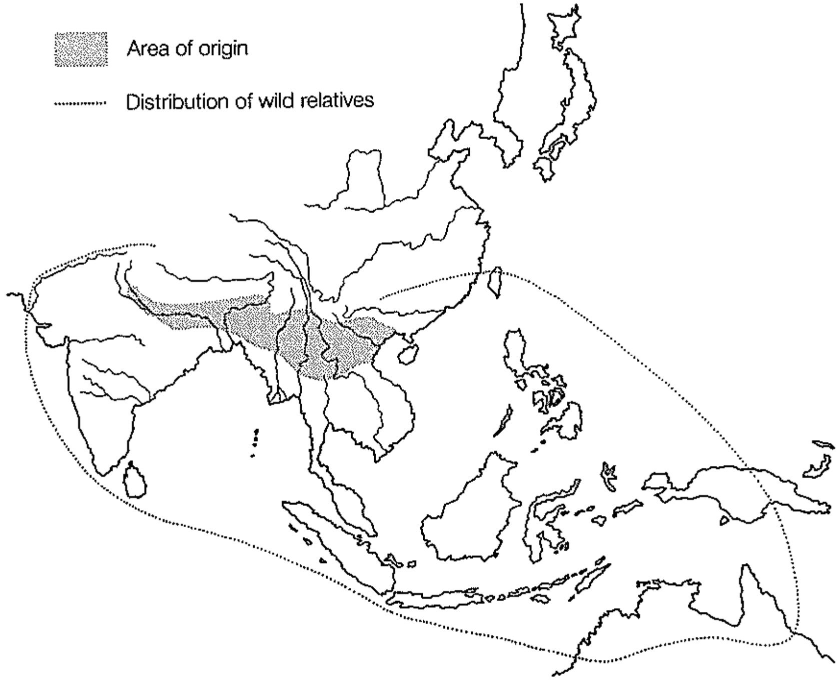

Figure 1.1 Area of origin of domesticated rice
(from Chang 1976a)

domestication somewhere in the piedmont zone of Assam, Upper Burma and Thailand, Southwest China and North Vietnam.[3] There is linguistic and ethnographic evidence to suggest that the earliest staple foods grown in monsoon Asia were tuber crops and millets, which were later superseded by rice (Kano 1946). The earliest archeological finds of domesticated rice to date come from China, from the site of Hemudu in Zhejiang province (near Ningbo in the Yangzi Delta). Excavations began in 1976 and are still continuing. The earliest stratum of Hemudu village, which is situated at the edge of a marsh, has been carbon-dated to about 5000 BC; the sheer volume of rice remains shows that the villagers were not proto-farmers but relied heavily on cultivated rice as a food supply even at that early date (Zhejiang CPAM 1976, 1978; Zhejiang Prov. Mus. 1978; You 1979).

A great number of Central and Southern Chinese neolithic sites of slightly later date contain remains of domesticated rice, among them several fourth millennium sites in the Yangzi Delta and further upstream, and a couple of sites in Guangdong which may date back to

2000 or 3000 BC (Yang 1978). There are also two early sites in North Thailand, Non Nok Tha and Ban Chiang (dated to about 5000 and 4500 BC respectively), which 'strongly suggest the presence of rice-farming in the northeastern Thai plateau prior to 4500 BC' (Gorman 1977: 433).[4] Gorman suggests that the domestication of rice began in naturally marshy areas in upland Southeast Asia about 9,000 years ago and that, as their skills improved, early rice-farmers were able to occupy non-marshy sites such as Ban Chiang and Non Nok Tha. Such a hypothesis seems consistent with the evidence from China and Thailand, and from Vietnam, where wet-rice cultivation was established in the Red River Delta by the mid-third millennium BC or perhaps earlier (Higham 1984). There is also linguistic evidence for a domestication of rice in the extended piedmont zone of Southeast Asia.[5]

India was for long believed to be the original centre of rice domestication, not only because of the varietal diversity of Indian rices (Vavilov 1949: 29), but also because until recently the supposed remains of rice from sites of the great Harappan civilisation were, at 1800 BC, the earliest known in the world (Vishnu-Mittre 1974). The Harappan 'rice' remains proved to be a misidentification however (Reed 1977: 918), and with the earliest Indian evidence now dated to about 1500 BC (Vishnu-Mittre 1977: 585), there is a clear case for giving preference to the Southeast Asian piedmont zone as the original home of domesticated rice.

Rice cultivation was probably a rather late introduction to Japan. The earliest evidence comes from sites in the southern island of Kyūshū which can be dated back to about 300–400 BC,[6] and from Kyūshū it spread gradually northwards, reaching the northern tip of Honshū before the Yayoi period ended in the mid-third century AD (Sahara, forthcoming; Tamaki and Hatade 1974: 58). Japanese rices are assumed to have originated in the Yangzi Delta, and there are three possible routes by which they might have reached Japan: overland through North China to Korea and then by sea; by sea from the Yangzi Delta to Korea and thence to Japan; or by sea from the Yangzi Delta directly to Kyūshū. The second hypothesis is currently favoured on the basis of associated tool typologies (Gina Barnes, pers. comm. 1984).

As we have seen, rice was cultivated from very early times on the mainland of Southeast Asia, but tuber crops or millets remained the staple crops of much of the Malay peninsula and Indonesian archipelago until rather late. The magnificent carvings of Borobudur (*c.*ninth century AD) depict millet but not rice, and rice seems to have been introduced to Java, not by land through Siam and then Malaya, but by sea from India during the later period of Hindu influence. Irrigated rice appears to have been introduced to Java in medieval times (perhaps before the establishment of the kingdom of Majapahit in the thirteenth century), whence it spread gradually to the scattered communities of the Southern Malay peninsula, though dates for this are generally uncertain (Hill 1977: 20–7; van Setten 1979: 1–9). However the northern kingdoms of Malaya, Kedah and Kelantan, seem to have adopted wet-rice cultivation somewhat earlier, deriving their skills from the mainland Southeast Asian tradition (unlike the other Malay and Indonesian regions, which refer to wet-rice fields as *sawah*, the Northern Malays use the term *bendang*). Furthermore in early medieval times a sophisticated system of wet-rice cultivation flourished on the Songkla peninsula in Southern Thailand, an area which probably had close trade relations with the Cambodian state of Funan (Stargardt 1983).

Although rice was a relative late-comer to the outer fringes of the Far Eastern world, it always arrived to stay. Once people became accustomed to eating rice they were loath to change back to other foods, and once they had built rice-fields on their land they were understandably reluctant to abandon them. The adaptability of the rice-plant meant that its cultivation was not confined to well-watered river valleys or deltas: it could be grown on steep slopes cleared of virgin forest in Borneo, along deeply flooded river-banks in Burma and Bangladesh, or on salt-marshes won back from the sea along the China coast. Under such difficult conditions as these crops might be small, but where conditions were slightly more favourable rich harvests could be had, and most of the great civilisations of the Far East, the Chinese dynasties, the kingdoms of South India and Ceylon, the Angkorian empire, Srivijaya and many more, were founded on the wealth of their rice-fields. Let us look at the natural characteristics of the rice-plant which account for its historical popularity and success.

Natural characteristics of rice

Rice is by nature a swamp plant, and by far the greatest number of varieties are grown in standing water, but there are also dry rices which are grown on steeply sloping hillside fields (Freeman 1970; Geddes 1976; Hill 1977). Generally speaking, dry or hill rice varieties will not grow in wet fields, nor can wet rices be grown in upland fields, but some interchangeable varieties do exist. It has been suggested that dry-rice cultivation developed earlier than wet, on the grounds that the techniques involved are less complex (see Watabe 1977: 16), but most botanists reject this on morphological grounds (Grist 1975: 27). Hill rice can only be grown by systems of shifting cultivation and does not, therefore, provide a suitable base for the development of complex technical systems or of the related social and economic organisations, and so our discussion will be confined to wet-rice systems.

Rice is an extremely adaptable plant, with an efficient system of air passages connecting the roots and the shoot which enables it to grow in dry upland soils, in irrigated fields, or along flooded river-beds. It is largely self-pollinated, but cross-pollination does occur in degrees varying between less than 1% and as much as 30% (Grist 1975: 72), and a very large number of wild varieties exists.[7] The range of variation in rice is so great that no internationally recognised system of classification has yet been developed, although repeated attempts have been made ever since the Rice Congress at Valencia in 1914 urged 'the formation of a real botanical classification of the varieties of cultivated rice'.[8]

Among the Asian domesticated rices, *Oryza sativa*, two sub-species are commonly distinguished, *indica* and *japonica*, both of which include glutinous and non-glutinous varieties. A list of the most important differences beween the sub-species is given by Grist (1975: 94). The contrasts which most immediately strike the non-specialist are that *indica* rices have longer, more slender grains which usually remain separate when cooked, while *japonicas* have shorter, rounder and more translucent grains which quickly become slightly sticky. The *indica/japonica*-distinction was first drawn in the late 1920s by a group of Japanese botanists, on the basis of morphology, hybrid sterility and geographic distribution. But some Asian rices, notably those of Indonesia, do not seem to conform to either category, and in 1958 a third sub-group named *javanica* was proposed to designate the *bulu* and *gundil* varieties of Indonesia (Grist 1975: 93).

In China both *indica* and *japonica* varieties have been cultivated since neolithic times (Bray 1984: 484). The earliest Chinese dictionary, the *Shuowen jiezi* of AD 100, was the first work to contain the terms *geng* and *xian* which have been used to designate *japonica* and *indica* rices in Chinese ever since (ibid.: 487). Not surprisingly, the majority of rice varieties grown in India are *indicas* and in Japan *japonicas*. Most rices grown in the tropical zones belong to the *indica* and *javanica* groups, which tend to have a fixed growth period. *Japonica* rices are highly sensitive to photoperiod, or day-length, and do poorly in the short-day tropics. They are, however, widely grown in North China, Korea and Japan. Altitude is also an important factor: a study of cultivated rices in Yunnan province in the Chinese foothills of the Himalayas showed that *indica* varieties predominated up to 1,750 m and *japonica* varieties over 2,000 m, while in the zone between 1,750 and 2,000 m intermediate varieties were found (Ding 1964).[9]

Rice (figure 1.2) has a number of advantages compared with many other food crops. First, it is very palatable, and is the only cereal which can simply be boiled and eaten without disintegrating into mush. Perhaps because of its flavour it has frequently been considered a luxury food: in medieval Japan peasants paid their dues to their lords in rice grown specially for this purpose, though they could afford to eat only millets themselves, and similarly in many parts of India today poor farmers sell their rice crops to the cities and buy cheaper grains for their own consumption.

The nutritional value of rice varies considerably according to type, environment and method of preparation, but generally speaking it is highly digestible and nutritious. Unmilled rice compares favourably with wheat and other cereals in its protein, fat, vitamin and mineral content, but unmilled or 'brown' rice has little sale outside the health-food stores of the West. It takes a long time to cook and is difficult to chew, and most rice-eaters prefer their rice to be not only hulled (removing the husk), but also milled and polished (removing all the coloured pericarp as bran). This leaves the grain white and shining. In polishing rice loses much of its nutritional value: highly polished rice contains only 7% protein, whereas rice that has simply been husked still contains nearly 10%.[10] Washing and cooking methods often deplete the nutrients further, and deficiency diseases such as beri-beri are not uncommon among consumers of rice too poor to supplement their diets with alternative sources of protein and vitamins. But just as Europeans traditionally regarded white bread as a luxury more desirable than brown, so most Asians wish their rice to be as highly polished as possible. The problem of nutritional deficiency has been exacerbated by the recent spread of efficient mechanised mills, for now almost all rice is highly polished, even in villages. Traditionally the Asian poor used their own hand-mills or bought inexpensive rice that was poorly polished and so they were, despite themselves, protected in some measure against deficiency diseases. They also garnished their rice with soy products, fish sauces and vegetables, which combined to make an impressively healthy diet compared with that consumed by the proletarians of urban or rural Europe (Fortune 1857: 42). So although modern analyses of the nutritional value of rice show it to be poorer in many respects than wheat, in fact many traditional Asian rice-based diets are nutritionally more than adequate.[11]

Rice is a relatively high-yielding crop even under adverse conditions. Provided the water supply is adequate, nitrogen-fixing organisms which occur naturally in the paddy-fields enable farmers to harvest up to 2 tonnes/hectare without applying any mineral fertilisers (Swaminathan

Figure 1.2 The rice-plant
(from a twelfth-century Chinese botanical work, the *Zhenglei bencao*, 1468 edn)

1984: 69). A very rough idea of the productivity of rice is given by the world production figures cited earlier, from which one can derive average annual yields of 1.95 t/ha for wheat and 2.75 t/ha for rice.[12] And this is not just a recent contrast. A map of one of the Gufukuji Temple's holdings in Kagawa prefecture, Japan, dating to 753, shows that dry fields were only one-quarter to one-third as productive as neighbouring rice-fields; even poor quality rice-fields yielded about one-third more grain than a dry field (Farris 1985: 107).

Of course yields may be much higher or much lower than those just mentioned. The highest rice yields in the world are in fact obtained in Australia (Grist 1975: 485), where as much as 7 t/ha may be had on fields which are sown with rice once every six or seven years, being used as pastures in the interim. In contrast, in parts of Malaysia where there is no irrigation and modern varieties and inputs cannot be used, subsistence farmers may get as little as 1.5 t/ha (pers. obs.).

But of special interest to farmers living on the margins of subsistence is that rice has a high yield to seed ratio. Wheat, barley and rye, the staple cereals of Northern Europe, bear heads with relatively few grains, say between 20 and 90; each plant will normally develop four or five tillers, giving a possible maximum of 400 or so grains per plant in all (Leonard and Martin 1963: 291). Theoretically, then, each seed-grain could produce 400 offspring. In reality, given the physiology of the plant and inefficient sowing techniques like broadcasting, in Europe up to the seventeenth or eighteenth century the ratio of crop to seed-grain averaged no more than 4 : 1 or 3 : 1, of which of course a high proportion had to be set aside as seed for the next crop (Slicher van Bath 1963: 382). A single panicle of rice may contain up to 500 grains, though 75 to 150 is more usual, and a well-watered plant on fertile soil can produce up to 50 tillers (Leonard and Martin 1963: 615); the number of grains produced from a single seed could thus easily average 2,000 in transplanted rice. Yield to seed ratios of 100 : 1 can be obtained even using such simple cultivation techniques as those practised in parts of Malaysia which have not seen the benefits of the 'Green Revolution' (pers. obs.; Hill 1977: 134). Setting aside one-fiftieth or one-hundredth of the rice harvest for seed-grain is much less of a hardship and a risk for subsistence farmers, then, than keeping enough wheat for sowing.

One reason why rice gives high annual yields is that it is often possible to grow two or even three crops a year in the same field. This does not mean that the annual yield is thereby doubled or tripled, but it will certainly be increased significantly. Alternatively, overall output can be increased by draining the rice-fields after the harvest and planting crops such as wheat, vegetables or tobacco. Since a crop of transplanted rice may occupy the field for as little as two to three months, there is more scope for multi-cropping than when directly sown cereals like wheat, millet or maize are the main crop.

The possibilities of multi-cropping and the high yields of wet rice are consistent with very high land productivity, though this does depend on heavy inputs of labour. As a wet-rice farming system becomes more intensive the land's population-carrying capacity increases sharply, as do labour requirements. The intensification of rice-farming both permits and requires demographic increase. It is no coincidence that the most densely populated agricultural regions of the world, Java, the Tonkin Delta and the Lower Yangzi provinces of China, all have a centuries-long tradition of intensive wet-rice farming. No wheat-growing areas can sustain such numerous populations.

Rice-fields planted with a second crop generally give higher yields each season than those which are only single-cropped, thanks to the additional ploughing and manuring, and also to the beneficial effects of drying out the soil (Grist 1975: 44; Watabe 1967: 103). This fact is clearly appreciated by landowners in Northern Thailand, for example, who will often lend their rice-fields free to landless peasants in the dry season to grow soybeans or groundnuts (Bruneau 1980: 386). If the field is continuously planted with wet rice its fertility, unlike that of dry fields, will not diminish over time even if few or no fertilisers are used, for the nutrient content of the irrigation water, together with the nitrogenising power of the naturally occurring algae, are sufficient to maintain regular returns from traditional rice varieties. This is obviously an important consideration for a subsistence farmer.

So rice will allow poor farmers to produce reasonable yields from their land, at the cost, it is true, of heavy investments of labour, but without necessitating such capital outlays as the purchase of fertilisers. Another important consideration for subsistence farmers is the risks involved in production. If one may reap a hundredfold in a good year but three years out of four are bad, one's hold on life is bound to be precarious. Here again, rice offers significant advantages.

A very important risk-reducing factor in rice-growing is the enormous range of varieties available to farmers even in isolated areas. The number of cultivated varieties of *Triticum aestivum* (by far the most important of the six types of domesticated wheat) totals some 20,000 throughout the world (Feldman and Sears 1981: 98). There are about 120,000 cultivated varieties of Asian rice (Swaminathan 1984: 66). The great range of rice varieties derives in part from its natural propensity to diversify, but this propensity has been encouraged and channelled by the conscious intervention of rice farmers through the ages.

Rice-farmers usually grow several different varieties of rice in any one season, partly to provide for different requirements and partly as a means of minimising their risks. Different fields will suit different varieties depending on the soil, exposure or water supply. Late rains will mean that quick-ripening varieties must be planted instead of better-yielding slow-maturing rices. It is often desirable to rotate varieties to reduce the incidence of disease. Small quantities of special rice are required for ceremonies, while less desirable but sturdier varieties are grown for sale. Another very important factor which rice-farmers must take into account is timing: labour is in peak demand at transplanting and harvesting, water (also a limited commodity) at ploughing and just after transplanting. If a number of different varieties are planted, then the requirements of water and labour will be spread over a more manageable period. Thus an Iban family would commonly plant 15 or more varieties of rice (Freeman 1970: 188); Lüe farmers in Northern Thailand grow various types of glutinous rice for their own consumption and of non-glutinous rice for sale according to carefully calculated harvesting schedules (Moerman 1968: 150); and in eleventh-century Anhui (Central China) poor farmers grew large-grained *japonica* rices to pay their taxes, and *indicas* for their own consumption (Bray 1984: 491).

Rice-farmers, then, have traditionally used a wide range of varieties both as a policy to ensure subsistence and as a strategy to increase their income. Where rice is the main commodity, as in the Northern Thai village of Ban Ping, or in San-lin village in Central Taiwan, farmers wish to maximise their rice yields; indeed even today they will often make their financial calculations in terms not of cash – whose value to such farmers in a fluctuating market or inflationary economy appears highly unstable – but of rice (Moerman 1968: 153; Huang 1981: 44). Where other sources of income predominate, farmers wish to plant rice varieties which free the rice-fields sufficiently early for them to plant commercial crops such as tobacco, vegetables or sugar-cane, or varieties whose peak labour requirements will not clash with other activities such as the cultivation of cash crops in dry fields (e.g. Bruneau 1980: 407).

Since their requirements are so specific and varied, it is not surprising that rice-farmers have always devoted considerable attention to the development and maintenance of desirable strains according to a number of criteria such as yield, habitat, flavour, growth period and season, resistance to flood, drought and disease, glutinous or non-glutinous endosperm, and fragrance. There are black and red rices as well as white. 'Rouge-red rice is soft, fragrant and sweet, and when it is cooked it turns a uniform red in colour. It is one of the best of the late rices. One variety tolerates saline conditions and is ideal for brackish fields by lakes or near river mouths', says the *Qun fang pu*, a seventeenth-century Chinese botanical work (Bray 1984: 494). Rices such as these were used to reclaim the swamp-lands of Hong Kong by migrant Chinese fleeing from the Mongols in the thirteenth and fourteenth centuries (Watson 1975: 30).

The 'glutinous' characteristic is one that has been much valued by Asian rice-farmers. 'Glutinous' varieties in fact contain no gluten; the stickiness of the cooked grain is generally assumed to result from the presence of dextrin and a little maltose as well as starch in the endosperm (Grist 1975: 100). Glutinous rice is highly valued as a ceremonial food and as the chief ingredient in rice 'wines' or beers. Cakes made of glutinous rice are exchanged at weddings and religious festivals all over Asia. In Malaya a large cake of glutinous rice, coloured brilliant red, yellow or purple and decorated with eggs and flowers, is offered to the bride as a symbol of fertility. In South China cakes of glutinous rice, wrapped in broad bamboo leaves and steamed, are exchanged on the day of the Dragon Boat Festival. Most Asians eat ordinary rice as their staple, but some mountain-dwellers prefer the glutinous kind, regarding it as more nutritious – if inclined to make the brain sluggish. In Northern Thailand this dietary distinction is seen by the local peasants as a mark of both ethnic and political identity: only effete southerners, soldiers or government officials, eat non-glutinous rice, and though local farmers grow the higher-yielding non-glutinous varieties for sale, they always take care to plant enough glutinous rice for their own consumption (Moerman 1968).

From the point of view of the cultivator, one of the most important differences between rice varieties is the ripening period, which may vary between 90 and 260 days. *Japonica* rices take a fixed period to ripen regardless of the date at which they are planted, but most *indicas* are photosensitive and will always flower at a particular date (Grist 1975: 84). It is therefore easier to breed quick-ripening varieties of *indica* than of *japonica*. Quick-ripening varieties are especially useful where the water supply is uncertain or insufficient. They also make multi-cropping possible, but they usually yield significantly less than medium-or long-term rices. The great exceptions, of course, are the recently developed 'high-yielding varieties' (HYVs) which have come to play such an important part in Asian rice production since the 1960s. These are derived from semi-dwarf mutants of *indica* rices; they are mostly quick-ripening, permitting double-or even triple-cropping, and they respond very positively to chemical fertilisers, often yielding more than half as much again as traditional varieties.

Where deep flooding rather than inadequate water is the problem, in

deltas or lakelands for example, the introduction of floating rices has sometimes proved effective. Floating rices are most extensively grown in the deltaic plains of Burma and Bangladesh; in Bangladesh they constitute almost one-quarter of the total rice crop (Oka 1975b: 279), and about 25 varieties are known (Grist 1975: 140). They are also important in the other flood-plains of Southeast Asia, and the introduction of floating rices to the Burma Delta at the end of the nineteenth century was one of the major agricultural innovations of the colonial period (Adas 1974: 130). And in pre-revolutionary Cambodia, although floating rice occupied only a small area (some 85,000 out of over 1 million hectares under rice), it had great economic significance, for unlike ordinary rices it was grown almost exclusively for sale. The crop was supposed to be very ancient in the Plaine des Lacs, but was only introduced to the south of Cambodia by French officials in the late nineteenth century (Delvert 1961: 329).

Yields of floating rice in Cochinchina generally were quite high: 2 t/ha as opposed to 1.8 t/ha in single-cropped and 2.6 t/ha in double-cropped fields (Henry and de Visme 1928: 52). In parts of Thailand floating rices will yield up to 5 t/ha if transplanted, even though no fertilisers are used; average yields in areas prone to flood are likely to be much lower, but at 2 t/ha still higher than non-floating rices in the same vicinity, which yield only 1.45 t/ha (Oka 1975b: 282). So far little attention has been devoted to breeding improved varieties of floating rice, despite their great potential importance, but work in this field is now in progress (ibid.: 284 ff).

Selection techniques

Since rice-farmers' requirements are so specific and vary so widely, it is not surprising that they have always devoted considerable attention to the development and maintenance of desirable strains. As cross-pollination does occur in varying degrees, and since wild rices are common in many of the areas where rice is cultivated, in the natural course of events one would expect rice cultivars to evolve and change continuously. Human selection has thus been crucial in maintaining desirable strains and selecting new cultivars. The techniques of rice-farming lend themselves particularly well to selection.

One of the simplest methods of improvement is to pick out the best panicles at harvest time and set them aside for seed-grain. This process was probably facilitated from very early times by the use of the reaping-knife. A small, flat knife with a curved blade, the reaping-knife is held in the palm of the hand and the heads of grain are cut off just below the ear, one by one, by drawing the stem across the blade with the index finger (figure 1.3). Stone, shell and pottery reaping-knives are common in neolithic sites throughout China and Japan, and knives with small metal blades were used to harvest rice throughout much of Southeast Asia until very recently. Ethnographers have frequently linked this knife specifically with the cultivation of rice, for its use is often accorded ritual significance by rice-growers: Malay farmers, for instance, believed that since it was hidden in the palm of the hand, unlike the naked blade of the sickle it would not frighten away the 'rice soul', *semangat padi*, without which the seed-grain could not grow (Hill 1951: 70). But the reaping-knife is also used by Asian farmers growing foxtail and broomcorn millets (Fogg 1983; *Wang Zhen nongshu* 1313: 14/6b), the cultivation of which preceded that of rice in many parts of East and Southeast Asia. However, all the early domesticated cereals of the Far East, including rice, have large seed-heads or panicles, are naturally free-tillering and tend to ripen unevenly. In such circumstances it is not desirable to reap all the heads from a single plant simultaneously: it is better to gather the heads individually as they ripen, for which purpose a small knife is preferable to a sickle. And if each panicle is cut individually in this way, then it is easy for the farmer to pick out specially fine heads, or to select seed-grain from a plant which has ripened earlier than the rest and may thus produce quick-ripening offspring.

Transplanting is another stage of rice cultivation at which the farmer has a chance, not so much to select the best plants, as to eliminate sickly plants or mutants, and so maintain reasonably pure strains.

A third stage of possible control in traditional rice-farming occurs just before sowing, when the seed-grain, which has usually been stored in the ear as a protection against insects and mildew, is taken out and husked. It is then common practice to soak the seed briefly in order to separate out empty or rotten kernels and weed-seed. Sometimes clear water is used; in early and medieval China it was commonly believed that water obtained from melted snow was especially beneficial: 'It will immediately dissolve the hot properties of the grain so that the young shoots will be unusually handsome' (Song 1966: 11). Later on a brine solution was often used to test the seed:

First construct a bucket of 2 gallon capacity. (Separately prepare a fine-meshed bamboo basket slightly smaller than the bucket.) Put in 1 gallon of water and add salt. For ordinary rice use 120 ounces of salt, for glutinous rice use 100. Stir with a bamboo brush for five or six minutes until the salt has dissolved, then insert the basket into the bucket and gradually pour in 4 or 5 pints of seed, not too much at once. Skim off the empty kernels that float to the surface with a bamboo strainer.

Figure 1.3 Harvesting-knife, ketaman, *used in Kelantan*
(photo courtesy A. F. Robertson)

Repeat several times until no floating seeds remain, then draw out the basket, put it into another vat of water and rinse away the salt. (Zeng 1902: 1/18b)

In Malaya the strength of the brine was tested by floating a duck-egg in the water, and in post-revolutionary China a hen's egg was used to test a thin suspension of clay. Modern agronomists recommend specific concentrations of salt, ammonium sulphate or lime as more accurate than the folk methods just described (Bray 1984: 246). Even though the grain has already been selected at harvest the process of soaking is not superfluous, for there may be significant differences in speed of germination and in flowering time even between grains taken from the same ear, and the heavier grains can be relied upon to flower and set more quickly (Ding 1961: 310). This is of particular importance where quick-maturing varieties are being grown.

In the past it was usually peasant farmers who selected and developed new strains of rice and passed them from hand to hand. Specially successful varieties might sometimes travel great distances in this fashion: for example in seventeenth-century China a variety known as 'Henan early' was recorded as far away as South Fujian, perhaps 750 miles away (Ho 1959: 173).

An interesting example of the development of quick-ripening varieties is provided by the so-called 'Champa' rices. Champa was an Indochinese state to the south of Annam, known to the Chinese as early as the first century AD for having rices so precocious they could be cropped twice in one year (Bray 1984: 492). There is also archeological evidence that double-cropping was practised even earlier, in the Dong S'on period (Higham 1984: 105). By the sixth century the Annamese apparently possessed such a wide range of wet and dry, early and late varieties that they could grow rice all the year round, but the quick-ripening varieties gave very low yields while requiring just as much labour as the other sorts (Amano 1979: 193). They did, however, have very moderate water requirements: they would grow in poorly watered fields, did well as dry crops when grown in hilly regions and were generally highly resistant to drought. Many farmers must have grown them, if not as their main crop, at least as a form of insurance.

The Champa rices had spread northwards as far as South China by the medieval period, passing from farm to farm, for when the Song emperor Zhenzong decided to encourage their cultivation in the Lower Yangzi region he sent not to Annam but to Fujian province for 30,000 bushels of Champa seed; this was in AD 1012. The Champa rices, unlike those most popular in much of China at that time, were *indicas*, and at first they gave consistently lower yields than most traditional

Chinese varieties. But peasants quickly selected and developed higher-yielding varieties to grow in the well-watered lowland fields. By the end of the Song dynasty, some 250 years after their official introduction, later-ripening and more prolific Champa rices had been bred and soon the range was as wide as for any other type of rice.

Although it was the Song government which first introduced the Champa rices to the Yangzi Delta, it was through the efforts of individual peasant farmers that the best varieties of Champa rices were developed. In recent times, however, the breeding and even the choice of rice varieties has become increasingly a matter for officialdom.

The Japanese set up agricultural research stations where the best 'native' varieties were crossed to produce 'improved' varieties as early as the 1870s (Dore 1969: 98); these improved rices were distributed to local farmers, together with detailed instructions as to their cultivation, through the recently founded Agricultural Associations. In the early 1920s the Japanese authorities introduced high-yielding *japonica* rices to Taiwan to replace the local *indicas*, which they considered insipid (Huang 1981: 59). Many Taiwanese farmers adopted the new *japonica* rices enthusiastically, for as they were mostly exported to Japan they commanded almost double the price of local rices (Wang and Apthorpe 1974: 163), but Taiwanese consumers continued to prefer the *indicas*, which offered farmers the additional advantage of requiring fewer fertilisers. When the Japanese first occupied Taiwan in 1895, 1,365 varieties of rice, all *indicas*, were grown on the island. Today many farmers grow *japonicas* in the main season and *indicas* in the off-season, and a 1969 report stated that only 86 *indicas* and 53 *japonicas* were then grown on Taiwan (Huang 1981: 48). Seed of the *japonicas* is these days distributed through the Farmers' Associations; the villagers do not keep the *japonica* seed themselves as they say it will deteriorate. However they refuse to use the *indica* seed bred at the Agricultural Research Station. Instead they select their own, sharing out seed from high-yielding fields; they say that, like the native fowls, the original native rices will never degenerate (Wang and Apthorpe 1974: 163).

In China, in contrast to Japan and its colonies, the emphasis was on improving *indica* strains. Breeding programmes were first set up in the universities in Canton and Nanking in 1925, and in 1934 a national breeding programme and distribution service was set up by the National Agricultural Research Bureau (Shen 1951: 199). Traditional *indicas*, in China as elsewhere, are tall and have a tendency to lodge (that is, to fall over if wind or rain are too strong). The Chinese breeders concentrated on producing new varieties from semi-dwarf mutants, and had developed high-yielding types by the early 1960s, a few years before similar 'miracle rices' were developed by the International Rice Research Institute (IRRI) in the Philippines (Harlan 1980: 307).

The Chinese and Japanese policy had been to select the best varieties available locally and to improve them through pure-line selection. IRRI, founded by the Ford and Rockefeller Foundations in 1960, was able to draw on the best available strains from many nations for its breeding programmes. The chief characteristics of the new heavy-yielding varieties (HYVs) are their short growing period, their pronounced response to chemical fertilisers and of course their high yields. The early HYVs had a number of shortcomings, chief among them being their lack of flavour, their inadaptability to local conditions and their vulnerability to disease. Since they were often grown as part of a 'technological package' which imposed virtual monoculture of a single variety over large areas (we shall discuss this further in chapter 4), such shortcomings were sometimes exacerbated to the point where yields were hardly greater or more reliable than those of the traditional varieties. But more careful attention to local testing and adjustment, and to breeding for reliability as well as simply high yields, has brought about enormous improvements:

> IR36, a variety now grown on more than 10 million hectares of the world's rice land, is a result of this strategy. It resists four major rice diseases and four serious plant pests, including brown planthopper biotypes 1 and 2. It grows well in a variety of cultural environments, tolerates several adverse soil conditions, has grain of good quality and matures in 110 days, which enables farmers to harvest as many as three crops in one year on irrigated paddies. IR36 is the progeny of 13 different varieties from six nations. (Swaminathan 1984: 70)

Both insect pests and disease organisms show remarkable rapidity in adapting themselves to attack resistant varieties. It is often wild or primitive crop varieties which exhibit the greatest capacity for long-term resistance to pests and diseases, and a continuous supply of genetic material is necessary to ensure successful and sustained breeding programmes (Chang 1976b). Most Asian rice-growing nations started national collections of rice varieties in the 1930s, but these collections tended to concentrate on commercial varieties and to neglect the wild and primitive strains whose germ plasm is the most useful for breeding purposes. Only in the 1960s did IRRI's germ plasm centre start systematically collecting and classifying wild and cultivated rices from all over the world; by 1983 their collection included '63,000 Asian cultivars, 2,575 African rices, 1,100 wild rices and 680 varieties maintained to test genetic traits. Thousands of breeding lines with one or more desirable traits are also preserved' (Swaminathan 1984: 67).

IRRI has provided the world with many of its most successful rice varieties in recent years, but research at national level is also producing interesting results. Most rice-breeding programmes are based on the technique of crossing selected parents to achieve a new variety which combines their desirable characteristics and which will, in principle, breed true. But since 1970 Chinese scientists, using male-sterile plants, have overcome the difficulties inherent in working with this mainly self-pollinated crop and have managed to produce hybrid rices (Harlan 1980: 302). These may eventually produce results as spectacular as those achieved with other hybrid crops like maize.

The drawback of hybrids is that while the first generation is more vigorous than either of its parents, subsequent generations quickly lose the desired characteristics. This means that the hybrid seed must be produced in laboratories, and that farmers must buy new supplies every year. In any case it is becoming generally true that rice-farmers no longer have any direct part in selection or breeding. If the improved variety they choose to grow is particularly stable, then they may be able to produce their own seed-grain at least for a few years; otherwise they have to purchase their seed from a Farmers' Association (Harriss 1977: 147). But many poorer farmers cannot afford this, and pleas have been made for the professional breeders to develop more stable varieties, as well as to consult more carefully with local farmers to take their requirements into account (Chambers 1977: 405). Plant-breeders today have at their disposal enormous resources which should enable them to produce the right variety for every situation, but given the time and expense involved it is possible they may choose to serve the peasant farmers' interests less well than their own. In any case it is clear that the number of rice varieties of which a late-twentieth-century rice-farmer disposes is far less than it would have been even thirty years ago. But the new varieties often combine the advantages of several traditional varieties, so in a sense the farmer's choice has not been reduced, but has become less direct.

In conclusion, we see that rice offers several significant advantages to the peasant farmer. Although we shall see in subsequent chapters that it is hard work to grow, generally requiring more labour than other crops, it is also the highest yielding of all cereals after maize, but has superior nutritional value (Huang 1981: 49). It is highly adaptable, can be grown under almost any conditions, does not necessarily require fertilisers (although it does respond well to their use) and will produce as many as three crops a year if there is sufficient water, without exhausting the fertility of the paddy field. The techniques of rice cultivation are such that farmers themselves have been able to select for desirable traits through the centuries, and so a very wide range of cultivars has been developed. By keeping a range of varieties in stock the farmer can protect himself in fair measure against the risk of drought or flood, and can also increase his income, either by producing more rice, or by combining rice cultivation with more profitable activities like cash-cropping.

The distinctive feature of wet-rice cultivation is the degree of intensity with which land can be used. If quick-ripening varieties are used, as many as three crops of rice a year can be grown even by farmers who do not have access to chemical fertilisers, for the water supply provides nutrients naturally. This means that once rice cultivation is established in a region it will sustain population growth almost indefinitely. No other crop has such a great population-carrying capacity, and this is one of the factors to which we can attribute the success and popularity of rice. Although it is possible to increase yields even with traditional inputs alone, as we shall see in the next chapter the techniques of rice-farming are such that intensification is achieved, not through high levels of capital investment, but rather through using increased amounts of labour.

2

Paths of technical development

As societies develop and their populations grow, so too their agriculture expands and develops to produce more food, and eventually to support the growth of commerce, manufactures and industry. Increases in agricultural production may be achieved through expanding the area under cultivation or through improving the productivity of existing farm-land. Where land is freely available, where agricultural labour is scarce, or where more attractive employment than farming beckons, innovations in farming practice will tend to improve the productivity of labour. But if land is scarce and labour plentiful, then farmers will usually consider the productivity of land more important.

Asian rice cultivation is generally considered labour-intensive and technologically primitive compared to the advanced farming systems of the West today. It is certainly true that the historical development of Asian rice cultivation techniques has followed a very different pattern from that of European wheat cultivation (outlined in appendix A). In both cases, however, the long-term trend was the same: more grain was produced. But in Europe many of the most striking advances increased the productivity of human labour by substituting animals or machines, taking advantage of the essentially extensive nature of the farming system to introduce economies of scale. As we shall see in this chapter, by their nature the wet-rice systems of Asia respond positively to increases in the application of labour, but are not as susceptible as Western farming systems to capital-intensive economies of scale. Instead, highly sophisticated management skills were developed which brought about enormous improvements in rice yields.

This chapter explores the dynamics of wet-rice systems: the technical means by which increases in rice production may be achieved, and the inherent trend towards intensification of land-use and small-scale management.