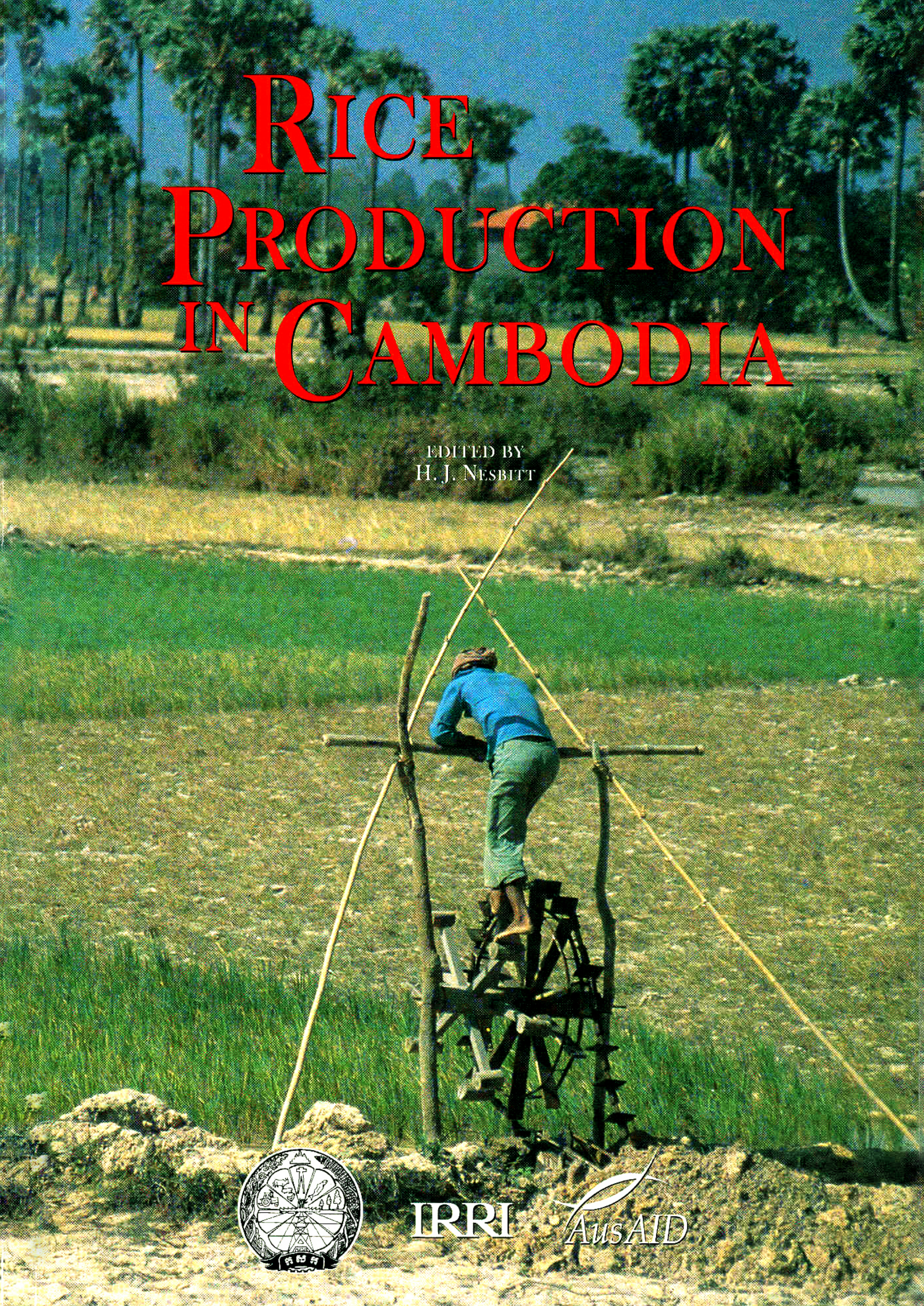
Rice Production in Cambodia

Edited by
H. J. Nesbitt



IRRI

AusAID

RICE PRODUCTION IN CAMBODIA

EDITED BY
H. J. NESBITT

Cambodia-IRRI-Australia Project
1997

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 16 nonprofit international research centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization of the United Nations (FAO), the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). Its membership comprises donor countries, international and regional organizations, and private foundations.

As listed in its most recent Corporate Report, IRRI receives support, through the CGIAR, from a number of donors including UNDP, World Bank, European Union, Asian Development Bank, Rockefeller Foundation, and International Development Research Centre, Canada, and the international aid agencies of the following governments: Australia, Belgium, Canada, People's Republic of China, Denmark, France, Germany, India, Indonesia, Islamic Republic of Iran, Japan, Republic of Korea, The Netherlands, Norway, Philippines, Spain, Sweden, Switzerland, United Kingdom, and United States.

The responsibility for this publication rests with the International Rice Research institute.

P.O. Box 933, Manila 1099, Philippines
Phone: (63-2) 845-0563, 812-7686
Fax: (63-2) 891-1292, 845-0606
Email: postmaster@irri.cgnet.com
Home page: http://www.cgiar.org/irri
Riceweb: http://www.riceweb.org
Riceworld: http://www.riceworld.org
Telex: (ITT) 40890 Rice PM
(CWI) 14519 IRILB PS
(RCA) 22456 IRI PH
(CWI) 14861 IRI PS

Cambodia-IRRI-Australia Project
PO Box 01, Phnom Penh
Cambodia
Tel: (855-23) 426465, 426229, 364115
Fax: (855-18) 810 796
EmailIRRI-CAMBODIA@CGNET.COM

Office
14 Monireth Street,
Phnom Penh, Cambodia

The Cambodia-IRRI-Australia Project is a collaborative project utilizing resources from both the International Rice Research Institute (IRRI) and the Department of Agronomy (DOA) within the Cambodian Ministry of Agriculture, Forestry, and Fisheries (MAFF).

Funding for the IRRI portion of the project is provided by the Australian Agency for International Development (AusAID).

Suggested citation:
Nesbitt, H.J., ed. 1997. Rice production in Cambodia. Manila (Philippines): International Rice Research Institute. 112 p.

ISBN 971-22-0100-7

Foreword

Rice production in Cambodia has passed through a series of impressive developments and setbacks over the past one or two thousand years. During this century alone, Cambodia rose to being one of the major rice exporters of the world and then slumped into a period during which a vast percentage of the population had little to eat. Recent democratic elections and the opening of the economy auger well for Cambodian agriculture and a greatly expanded rice production base is expected in the near future.

This book presents a brief history of rice in the Cambodian economy and gives considerable detail on the country's rice-growing ecosystems. Included are descriptions of the topography, climate, and soils on which the crop is grown, details of the biotic and abiotic factors influencing productivity, farmers' management practices, current and potential scope for farm mechanization, rice-fish interactions, and some discussion on the constraints to increased production.

The results of considerable agronomic, social, and economic research conducted on rice ecosystems over the past decade are presented. These update readers on the latest technologies which can be utilized for improved production from sustainable rice-based farming systems and provide a basis on which future developments can be gauged. Results of the surveys conducted during this period are presented along with summaries of newly developed soil description techniques, details of the latest released varieties, and improved farming systems practices.

Senior authors of contributions to *Rice production in Cambodia* were Dr. Harry Nesbitt, agronomist/project manager; Dr. Peter White, soil scientist; Dr. Edwin Javier, plant breeder; Dr. Gary Jahn, integrated pest management specialist; and Mr. Joe Rickman, agricultural engineer; all from the Cambodia-IRRI-Australia Project (CIAP). An additional chapter discussing the interactions between rice and fish is presented by Mr. Rick Gregory and Mr. Hans Guttman from the Asian Institute of Technology. These contributions were not possible without close collaboration with employees of the Department of Agronomy, Department of Agricultural Engineering, Department of Fisheries and Provincial Agricultural Offices of the Ministry of Agriculture, Forestry, and Fisheries.

The book was edited by Tess Rola, with graphic design by Doris Rifareal and cover design by Juan Lazaro IV, Communication and Publications Services, IRRI.

The Australian Agency for International Development (AusAID) is gratefully acknowledged for funding this publication.

MINISTRY OF AGRICULTURE, FORESTRY AND FISHERIES

IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

AusAID
AUSTRALIAN AGENCY FOR INTERNATIONAL DEVELOPMENT

Contents

Rice in the Cambodian economy: past and present

K. HELMERS

Rice is the staple food of Cambodia and, considering food security, is its most important field crop today. The English phrase "to eat" is *pisa bei* in Khmer, which literally means "eat rice." This chapter outlines the history of rice in Cambodia and examines the role of rice in the economy at the national and farm household levels in the 1990s.

History of rice production

Precolonial period

Khmer farmers have been growing rainfed rice for at least 2,000 yr, possibly longer in the case of upland rice. Historians believe that rice-growing technologies may have been imported into Cambodia along trade routes from India. Irrigated rice production technologies were introduced 1,500 yr ago (Chandler 1993). Farmers integrated rice production into their existing systems of land use which had developed since prehistoric times. These activities included slash-and-burn agriculture, livestock raising, fishing and hunting, and gathering. A prehistoric river and coastal trade also existed, involving low-bulk, high-value forest products such as ivory, spices, hides, and aromatic woods (Chandler 1993).

The Angkorian period, from the 9th to the 14th centuries AD, witnessed the rise of the greatest kingdom in Southeast Asia in Cambodia. It became unified and gained vast territories from neighboring empires. The center of Khmer population shifted from the northwest to the Tonle Sap Lake region, with the economic power of Angkor being based on rice agriculture (Plate 1). The system of rice production at Angkor, however, remains a subject of debate. Some historians contend that Angkor gained its power through dramatic and widespread innovations in rice irrigation technology. The centerpiece of the irrigation system was the great reservoirs and canals around Angkor Wat. Others contest this view, arguing that the great waterworks of Angkor were primarily for ceremonial and symbolic purposes. This view holds that the rice economy of the Angkorian empire was based on riceland expansion, the number of rice farmers who were subjected to taxation, and innovations in the control and use of mass labor (Grunewald 1992, Chandler 1993).

Between the 15th and 17th centuries, Angkor was abandoned as the capital and territorial and population gains were forfeited, including the loss of the lower Mekong Delta region to Vietnam in 1626. The center of Khmer population returned to the southeastern region of present-day Cambodia, and the basis of the economy reverted to the river trade in forest products, centering on the new capitals in the region of Phnom Penh. The great hydraulic works of Angkor were never repeated (Chandler 1993).

In the 18th and 19th centuries, rural life and rice production were dominated by war, rebellions, and violence as Thai, Vietnamese, and Khmer forces fought across Cambodian territory, destroying villages, killing and displacing villagers, and laying farming regions to waste (Chandler 1993). Rural rebellions were to persist into the French colonial era up to the 1880s, when one such revolt threatened Phnom Penh itself (Osbourne 1969).

In general, for precolonial Cambodia, information on the social and economic situation of the Khmer rural people were lacking. It appears that existing rice technologies were generally adequate to meet farmers' needs. Population densities were low, and there was abundant food coming from forests and lakes. The farmers had also demonstrated their innovativeness, adopting rice production technologies which originated in India and adapting these to the poor soils, erratic rainfall, and complex hydrology of Cambodia. They developed specialized rice production systems for growing deepwater rice, upland rice, flood recession rice, and rainfed lowland rice. Within each farm unit, fields of different water availability (high, medium, and low fields) were planted to varieties of different duration (early, medium, and late) as a means to spread risk (Tichit 1981). Finally, farmers engaged in rice breeding and selection to meet local conditions. Over the centuries, farmers' selection had contributed to the approximately 2,000 traditional varieties of rice now identified as unique to Cambodia (Whitaker et al 1973; E. Javier, IRRI, pers. commun.).

At the same time, Khmer farmers faced three major threats to food security in the precolonial era. The unpredictability of the environment for rainfed rice production always presented a threat. The second threat was the tax levied by state officials on farmers' rice and labor, often with little concern for rural people's food needs (Chandler 1993). The third threat was the impact of periodic wars on rice production and rice farmers.

French colonial period

The French established a protectorate in 1863 and Cambodia became a component of the French Indochina Union with Laos and Vietnam for the next 90 yr. Only in the period from the early 1900s up to 1941 did the French systematically implement an agricultural development policy after earlier delays. Rural conditions at the turn of the century featured "frequent famines and epidemics of malaria and cholera" (Chandler 1993). The basis of the colonial Cambodian economy was to be the export of agricultural products, particularly rice and livestock. These exports were to boost supply for the French agroprocessing facilities and international export trade system centered in Saigon-Cholon in Cochin China. Cambodia's role was to supply only low-cost raw materials, and a domestic agroprocessing sector was slow to develop (Thomas 1978, Tichit 1981).

The French plan to develop export rice agriculture in Cambodia was composed of two quite different strategies. Indeed, two very different subsectors within the rice sector were created. The first subsector consisted of large-scale rice plantations that used modern farming methods under the control of French settlers. These plantations were established on land concessions and were concentrated in Battambang Province. They used hired labor. These concessions occupied more than 16,000 ha. The government provided extensive agricultural infrastructure to support the Battambang plantations up to the 1950s. A system of irrigation canals was created. The only two plant breeding and fertilizer research stations in the country and the only large research farm trial involved in testing rice mechanization technologies were established to serve these plantations. Because of the importance of Battambang Province in the rice export trade, a railway was constructed, linking it to Phnom Penh and then through river transport to Saigon (Delvert 1961). These plantations made an important contribution to rice exports and emphasized production of quality rice for French markets.

The second subsector consisted of almost the entire Khmer peasantry who continued to grow rice using traditional methods on small farmholdings throughout Cambodia. The total area covered by these holdings varied from 0.5 to 1.5 million ha during the colonial period. Here the French acquired rice for export not through advancement of rice technology but by depending on taxation and rice area expansion as the population increased. Indeed, Khmer farmers paid the highest per capita rates of tax in rice, labor, and cash than any farmers in French Indochina. The rice tax was the largest source of government revenues (Chandler 1993).

Little was achieved in technical innovation in rice production within the peasant subsector in the colonial era to develop the capacity of Khmer farmers (Thomas 1978, Tichit 1981). Rice yields remained stagnant at around 1 t ha^{-1} for 50 yr (Tichit 1981). As with other colonial powers, the French believed that peasants were incapable of developing or mastering innovations. This was the reason used to explain the lack of investment by the state in the peasant subsector (Osbourne 1969).

Rice research and extension services in the peasant subsector were virtually nonexistent, and state investment in agricultural infrastructure was minimal. Credit facilities were in the hands of village moneylenders who charged extremely high rates of interest. This practice led to widespread problems of indebtedness with the commercialization of agriculture (Kiernan and Boua 1982). Rural Khmers were neither provided with modern primary education nor technical education in the colonial era. Rather, Wat-based schools were funded at low cost to provide rudimentary learning and religious teaching. Rural girls were excluded from attending these schools (Chandler 1993, Kiernan 1985). There was very little training and employment of Khmers in skilled positions within public sector and private sector services to agriculture. These positions in colonial Cambodia were filled by French, Vietnamese, Chinese, and Sino-Khmers (Osbourne 1969, Chandler 1993, Kiernan 1985).

Exceptions to the general pattern of lack of development in this subsector included a program of barrage construction, which opened small areas for dry-season rice cultivation to some farmers. Attempts were also made to establish credit facilities in the 1920s to combat usury, although the result was unsuccessful (Delvert 1961). Some progress was also achieved in extending health and sanitation facilities to the rural population.

Khmer farmers proved responsive to rice market conditions in the colonial era. In the boom conditions of the 1920s, they earned good incomes from rice sales and increased production. The depression of the early 1930s led to a collapse by as much as 60% of rice export prices. Farmers responded by reducing the cultivated area by one-third of the national total and protesting to gain tax relief (Chandler 1993). Prices recovered somewhat later in the 1930s. However, the Japanese occupation from 1941 to 1945 brought new demands for rice for the Japanese war effort at low rates of return. Cultivating rice for export was often not a profitable activity for Khmer farmers in the colonial period (Thomas 1978). One study in the early 1950s analyzed the profit breakdown of rice exports through Saigon. Farmers received 26% of the profit, 34% went to intermediaries, 26% went to transport and processing, and the final 14% went to government tax (Hou 1955).

From the early 1900s until the early 1950s, the French secured rice exports that averaged from 50,000 to 200,000 t yr^{-1}, mostly in the form of rough rice (Tichit 1981). By 1940, Cambodia was the third largest rice-exporting country in the world (Munson et al 1968). Perhaps 30,000 t of exports came from the Battambang rice plantation subsector and the remainder from the peasant subsector. The area of rice cultivation had increased 340% to 1.7 million ha (Prud' Homme 1969). The Khmer population, benefiting from peace and improved medical services, had increased 200% to nearly five million. Security, however, was once more a major problem, causing economic disruption in the period 1946-53. Khmer Issarak forces, fighting for independence from France, had by 1953, rendered two-thirds of Cambodia out of the day-to-day control of the government (Chandler 1993).

Rice production, 1953-70

Cambodia gained its political independence from France in 1953. Peace was restored and the government, the Sangkum Reastr Niyum under Prince Sihanouk from 1955, set about ambitious development programs supported by western foreign aid in the decade up to 1963. During this period, the government assumed control of the large-scale French rice plantations in Battambang. With support primarily from the United States Agency for International Development (USAID), national water control infrastructure was improved. Irrigation schemes, barrages, canals, and reservoirs were constructed in Siem Reap, Kampong Cham, Kandal, and Kampot provinces. A USAID Rice Production Program began in 1955 and established six rice research stations for yield trials and seed production by its conclusion in 1960 (Munson et al 1968). It was claimed that by 1962, improved varieties bred from pure line selection of traditional varieties represented 20% of the rice crop (Dennis 1979). A government institution, the Office of Royal Cooperation (OROC), was established in 1956 to expand the role of rural cooperatives and to offer rural credit at an affordable price (Munson et al 1968).

Rural Khmers benefited from the massive expansion in primary level education and health services through the 1960s (Chandler 1993, PrudHomme 1969). In addition, three specialized educational institutions were established in the 1960s, offering secondary and tertiary level training in agronomy for government staff. Some of these technical staff were later posted to the provinces (Munson et al 1968).

Cambodia's farmers enjoyed a run of comparatively good seasons and rice sales brought good returns up to 1963. In this decade, the area of rice cultivation steadily expanded to 2.2 million ha; a gain of more than 500,00 ha. Rice production increased to levels of around 2.3 million t; a gain of 800,000 t. Yields posted a small increase of 200 kg ha^{-1} to levels approximating 1.1 t ha^{-1}. Milled rice exports reached levels in the range of 250,000-400,000 t yr^{-1}, although the quality of these exports remained constrained by low-quality milling (Prud 'Homme 1969, Munson et al 1968).

In 1963, further American aid was refused by Cambodia. In early 1964, foreign trade, including rice exports, was nationalized and placed under the control of a new state corporation given monopoly control, the Société nationale d'exportation et d'importation (SONEXIM) until 1969. The existing OROC parastatal became responsible for the purchase and processing of the rice export crop, which was then sold through SONEXIM. In addition, SONEXIM controlled the import of agricultural inputs including fertilizers and pesticides which were distributed for sale through OROC (Munson et al 1968, Whitaker et al 1973).

It was under this nationalized system of foreign trade that rice export levels reached an all-time high of more than 500,000 t in 1964 and 1965, with rough rice production levels at 2.5 and 2.75 million t. The government-fixed sale prices in these years were not very renumerative for farmers, and they were not paid promptly (Osbourne 1979). Instead, official exports were increased by the more organized collection of rice from farmers by OROC (Prud'Homme 1969). From 1966 to 1967, rough rice production levels fell to 2.3-2.5 million t and official exports declined to less than 250,000 t ha^{-1}. In 1968, while production reached 3.2 million t, official exports remained at only 252,000 t (Tichit 1981). While climatic conditions affected production levels, the relatively dramatic fall in official exports was due to the rise in rice smuggling to Vietnam. One estimate indicated that one-third of the 1966 rice export crop was sold in the black market and government rice tax revenues suffered accordingly (Osbourne 1979). In this unofficial market, farmers could obtain prices three times the official sale price through SONEXIM. The government response was to mount campaigns to forcibly collect rice at the official price. This led to armed rebellions by farmers in Battambang in 1967 and in Battambang and several other provinces in 1968 (Kiernan and Boua 1985).

The year 1969 was to be the last of this period of government. At this stage, rice production technologies for the most part remained traditional, and Cambodia's increase in production had mainly been achieved through expanding the area cultivated (Whitaker et al 1973). Large-scale irrigation had not yet spread and dry-season rice production accounted for only 5% (or 74,000 ha) of total rice area. Chemical fertilizer use nationwide totaled only 32,000 t, of which nitrogenous fertilizers amounted to only 5,000 t. Extension and credit services remained weak. Rice research, with French and Japanese aid, had only recently been started and was just beginning to experiment with the modern IRRI varieties and associated input packages. Research results were not yet available. Crop protection using pesticides had begun but it was not yet applied to rice. Agricultural mechanization had expanded to include the use of 1,500 tractors but remained largely confined to Battambang Province. A shortage of skilled technical and management staff in the agriculture sector likewise remained (IRBD 1970, Whitaker et al 1973).

Rice production, 1970-75

At the beginning of 1970, Cambodia achieved its greatest ever rice crop of 3.8 million t after a very favorable season in 1969. Barely 2 mo later, the Lon Nol regime came to power as the new Khmer Republic government, and Cambodia became fully engaged in the Second Indochina War, fighting Khmer Rouge and Vietnamese communist forces. This war that lasted up to 1975 devastated rice production, the economy, and the livelihoods of the rural people (Whitaker 1973, Shawcross 1979).

Much of the rural infrastructure and livestock were destroyed (Shawcross 1979). Official statistics show that between 1970 and 1974, rice area declined by 77% and rice production decreased by 84% of the 1970 level.

Rice production, 1975-79

The Khmer Rouge regime, known as Democratic Kampuchea, seized power on 17 Apr 1975. General studies of conditions under this regime are provided elsewhere (Shawcross 1979, Vickery 1984, Chandler 1993). Here the focus was on the agricultural development strategies envisaged by this regime and the results obtained. Agricultural development was central to the plan of the regime and focus was on developing rice production. The policy aimed to increase rice production by having two or more rice crops per year, substituting high-yielding rice varieties for traditional lower yielding varieties, and expanding the area of rice production into cleared forest lands. The average rice yield was to be trebled to 3 t ha^{-1} (Pijpers 1989, Chandler et al 1988).

A technically simple plan was enacted to achieve these objectives. All ricefields were to be leveled and made 1 ha in size. Irrigation canals were to be laid out bordering a 1-km^2 grid with integrated control structures and reservoirs. Trees were to be felled for new fields. The rural labor force was reorganized to conduct collective agriculture, supplemented by "new people" who had been forcibly evacuated from the cities. Specialized work units were developed for particular agricultural development tasks. Massive labor was used all over the country to develop irrigation systems and to clear new land for rice production, using mostly hand tools (Chandler et al 1988, Pijpers 1989).

The irrigation systems were a disaster due to lack of technical knowledge. One estimate indicated that by the mid-l980s, 70-80% of these structures were unusable or useless. Tens of thousands of people died during their construction (Pijpers 1989, Chandler et al 1988).

Rice research to develop high-yielding varieties was carried out by Chinese advisers at the research station in Battambang. Development of three varieties—Pram pi taek, Ramuon sar, and Champas kok—was announced on Phnom Penh radio. Pram pi taek yields were reported to be as high as 6.5 t ha^{-1} with good water control and 3-4.5 t with poor water control. There is no other report of the spread or performance of these varieties (Dennis 1979).

The development of rice production in Democratic Kampuchea was almost a total failure. Rice surpluses were generated in some circumstances but these were removed to be stockpiled by the army or were traded for weapons.

Rice production, 1979-89

In 1979, the liberation forces found the country devastated and under the threat of widespread famine. Millions of displaced and hungry people were returning to their homes and there were concerns that the rice crop for the year would not be planted (Shawcross 1984). The ranks of the pre-1975 skilled Khmer labor force of agricultural planners, technicians, and policymakers had been decimated. One estimate indicated that of the original 1,600 staff members, only 200 remained in 1980 and only 10 had university training. All agricultural research stations had also been destroyed or abandoned, and rice germplasm and technical data were lost (Mysliwiec 1988) (Plate 2).

The farmers themselves managed to avert immediate disaster through sheer hard work with limited foreign aid support. Through the rest of the 1980s, the People's Revolutionary Government of Kampuchea (PRK) continued to rehabilitate rice agriculture as a national priority.

A socialist development policy was pursued for agricultural development during this period, with very limited resources. Agriculture was organized on a collective basis, a means favored ideologically by Vietnamese advisers and regarded as the best way to share scarce agricultural implements and plow animals (Frings 1993). A private sector market in agricultural products was, however, permitted to function (Vickery 1986).

Solidarity groups known as *krom samakki,* consisting of 20-25 families, constituted the basic unit of production organized under village and commune administration. Agricultural land was collectivized and became state property. The rice harvest was distributed among adult workers according to the amount of labor contributed. Children, the old, and the incapacitated were also provided rice (Frings 1993, Vickery 1986).

In practice, collectivization was not vigorously pursued and a whole range of management styles developed within the different krom sammakis. The most intensively organized and least typical form used group labor for farming some land communally, using pooled livestock and implements and distributing the rice harvest from this land. For families who otherwise farmed parts of the communal land as a family, a second and more typical style involved mutual labor aid and sharing of implements and plow animals within the group. A third and very common option involved individual families farming communally owned land. In the mid-l980s, attempts were made to intensify collectivization within the groups but these efforts failed (Frings, 1993).

Progress in developing the technical agricultural capacity of the government was achieved during the 1980s, through training provided for several hundred Khmer students in universities in Eastern Bloc countries. Farmers were also able to obtain elementary schooling. kce production was gradually restored to meet basic needs, but production levels sufficient to ensure food security and to alleviate poverty remained elusive (Chandler 1993).

The Vietnamese and the Eastern Bloc also introduced improved rice varieties, such as IR36 and IR42, and provided some inputs such as machinery, fertilizers, and pesticides. These measures were of limited success, as a rice research service that could determine appropriate improved technologies for Cambodia had not been reestablished. The Cambodia-IRRI-Australia Project was established in Cambodia in 1987 to fulfill this specific need.

The PRK government was renamed the State of Cambodia in 1989, and new policies favoring a market economy were instituted. Private land tenure was established and communal lands were broken up and allocated to families. Land was divided equitably within each commune, based on the number of persons in each household. However, inequities in land distribution still occurred because of differences in land-to-family ratio between communes. The withdrawal of Vietnamese troops and further peace negotiations led to the Paris Peace Agreement in 1991, paving the way for democratic elections under the United Nations' supervision in 1993. The new government under King Sihanouk, called the Royal Government of Cambodia (RGOC), was installed.

The Cambodian rice economy in the early 1990s

Since the reforms of 1989, rice production in Cambodia has been conducted in a transition market economy. The structure of the economy in the early 1990s is presented in Table 1.1. The sectoral shares are affected by poor seasons for rice production over this period. Agriculture is the largest sector of the Cambodian economy, accounting for 45-50% of real gross domestic product (GDP). The industry sector has contributed 15-20% and the service sector, 33-36% of GDP in real terms (World Bank 1995). Agriculture represents a priority area in national development policy. Strategies have been formulated to improve food security, stimulate economic growth, increase rural incomes, and develop agricultural export industries (RGOC 1994, FAO 1994).

Three of the four largest subsectors of the economy in the early 1990s are within the agricultural sector. kce is the largest single subsector, contributing an average 17% of national GDP. Livestock is the third largest subsector, contributing 13% of GDP and other crops and rubber make the fourth largest subsectoral contribution, at 10% of GDP.

Table 1.1 Shares of real GDP at 1989 constant prices, by industrial origin. World Bank (1995).

Sector	% share of 1990 GDP	% share of 1992 GDP	% share of 1994 GDP (est.)
Agriculture	52.3	49.4	44.9
Rice	20.4	16.6	12.8
Other crops and rubber	10.0	11.5	10.1
Livestock	14.0	13.1	13.2
Fishing	5.1	4.5	3.9
Forestry	2.8	3.5	4.9
Industry (all subsectors)	14.9	16.3	19.6
Services (all subsectors)	32.8	34.4	35.6
GDP total (1989, billion riels)[a]	240.9	243.7	306.8

[a] US$1=2500 riels.

The allocation of cropland in Cambodia is summarized in Table 1.2. Rice production dominates the use of cultivated land in Cambodia, occupying 88% of total cropped area in 1993. Rubber, maize, and sweet potato are the most important nonrice crops. Seasonal variations in rice production are also dramatic, with more than 90% of rice cultivation occurring in the wet season and less than 10% in the dry season. In terms of national crop production tonnage, rice represents 81% of the total, four times that of all other crops combined and ten times that of the largest individual crop (FAO 1994).

A comparison of Tables 1.1 and 1.2 indicates that the economic role of rice production in the agriculture sector is proportionately smaller than its share of the cropped area of the country. This difference is due to several factors. Rice yields, averaging 1.3 t ha^{-1}, are low compared with those in most other countries. Cultivation of most nonrice crops is concentrated in more favorable environments, particularly in fertile fields near the major rivers with good access to water. Rice, in contrast, is grown throughout the country including the vast lowland plains, which are often characterized by poorer soils and inadequate access to water. According to the FAO (1994b), there are few alternative uses for much of this lower quality riceland. Perhaps up to 20% of the total rice area might be used for other crops, with the alternatives restricted to either jute or groundnut production. Moreover, there are market price differences for different crops, with other crops having a higher market value per unit than rice, and thus higher relative contribution to GDP. This is especially true not only of industrial crops (three to six times that of rice value per unit), but also of beans (two to four times that of rice value per unit) and some fruit and vegetable crops (FAO 1994b).

Marketing of rice is a major economic activity in Cambodia, although comprehensive studies of the rice marketing system are lacking and much of the quantum of trade is unrecorded. Rice is imported from and exported to both Vietnam and Thailand. There is also a domestic rice trade to meet demand in cities, towns, and rice-deficit rural regions. Rice is marketed for cash and is also traded as an exchange commodity for many goods and services in informal markets. Rice production tonnage dwarfs that of other crops, which means that rice probably has the largest economic impact on agriculture-related industry and service sector activities. These activities include agroprocessing, contract land preparation and harvesting, transport, and agricultural wholesale and retail trade (Cameron and Twyford-Jones 1995).

Table 1.2 Rice and other crop areas. Cambodia, 1993.

Crop type	Planted area (ha)	Yield (t ha $^{-1}$) [a]	% of total (rice or other crops)	% of total (all crops)
Rice				
Early-duration rice	240,500		13	
Medium-duration rice	644,200		34	
Late-duration rice	708,400		37	
Deepwater rice	108,500		6	
Upland rice[a]	35,000		2	
Wet season total	1,736,600	1.2	92	81
Dry season total	155,000	2.5	8	7.2
Subtotal	1,891,600	1.3	100	88.2
Other crops[b]				
Maize	48,000	1.3	19	2
Soybean	16,000	2.5	6	0.7
Mungbean	23,000	0.6	9	1
Sweet potato	50,000		20	2
Cassava	16,000	9.4	6	0.7
Tobacco	18,000		7	0.8
Groundnut	7,000		3	0.3
Sesame	13,000		5.1	0.6
Jute and kenaf	2,000		0.7	0.1
Sugarcane	6,000		2.1	0.3
Vegetables-other	na		na	na
Rubber	53,000	0.78	21	2.4
Subtotal	252,000	-	100	11.8
Grand total (all crops)	2,143,600	-		100

Sources: Bulletin of Agricultural Statistics. 1993, No. 4. [a]Estimate. [b]FAO (1994).

The rice market in Cambodia is characterized by a high degree of fragmentation and inefficiency. Causes of fragmentation include poor physical and communication infrastructure which limits the movement of goods and information. This gives rise to a mismatch between rice supply and demand across the country and over time. Price distortions reflect these imperfections. For example, in September 1994, it was found that rice was selling in Takeo Province for $US160 t $^{-1}$ less than in Phnom Penh which is only 90 km away, a differential far in excess of transport costs. This fragmentation also means that returns to farmers are frequently low, with most profit share accruing to traders, wholesalers, and retailers (Cameron and Twyford-Jones 1995).

The rice industry, like the other agriculture subsectors, has a low capital base. This adversely affects the extent of successful marketing. Formal bank credit is unavailable to small-scale producers and agribusiness workers who are the backbone of the industry. Credit availability in the rice market is dominated by informal moneylenders who typically charge rates of 20-30% per month on cash loans and 100% interest on loans of rice in kind over a 6-mo period. They remain in business as they provide easy and timely access to capital at the local level and face little competition in local credit markets. In 1995, none of Cambodia's 31 banks were involved in lending to agricultural producers and credit schemes of nongovernment /international organizations have reached only 2.5% of Cambodian villages (Cameron 1995).

Limitations in postharvest technologies also affect the operations of the rice market. Storage losses are high due to lack of control of moisture levels at storage and contamination and pest attack in low-quality storage facilities. Transport losses are also high due to poor packaging and handling. Finally, rice mills in Cambodia are inefficient, having a milling yield of unbroken rice of less than 60% of paddy by weight. This was attributed to the use of low-quality and poorly maintained milling machinery. Efficient milling should yield 70% of paddy weight in rice. The current net loss due to inefficient milling in economic terms is 9% of rough rice value (Cameron and Twyford-Jones 1995).

Human resources in services to agriculture remain a major constraint. The 36,000 public and private sector staff working in institutions that provide services to agriculture frequently lack education and training in technical fields, extension, and management. This is especially true of training in important areas such as high-quality technical training relevant to Cambodian conditions, modern modes of extension, and management operations in a market economy. Public sector performance in agriculture is further constrained by institutional limitations in management, a general lack of resources, and very low salaries (FAO 1994c, d; World Bank 1995b).

Characteristics of Cambodian rice farming households in the early 1990s

Rural households in Cambodia number 1.5 million and account for 85% of national population. Eighty-two percent of the rural labor force is engaged in agriculture, forestry, and fishing, and the vast majority of these households are engaged in rice production (UNDP/NIS 1995, FAO 1994). The average rural household size is 5.5 persons (common range is 3-7 persons). The average age composition of rural households are 44%, aged 0-14 yr; 52%, aged 15-64 yr; and 4%, aged 65 yr and above. The average adult labor force per household is 2.9 persons. The percentage of rural households headed by a female is estimated at 20% of the total number of households (UNDP/NIS 1995). Heads of farm households tend to be older (40-50 yr old) and have longer farming experience (20-25 yr) (Rickman et al 1995).

The average years of education for rural adults is 4.4 yr for males and 2.2 yr for females. Rural adult literacy rates, assessed at the simplest level of an ability to read and write a simple message, average 79% for men and 51% for women (UNDP/NIS 1995).

Farm households in Cambodia are engaged in a range of activities to secure food and income. These activities include rice production, other field crop and garden production, livestock production, hunting and gathering, fishing, wage labor and small business (Helmers and Bleakley 1996; FAO 1994, Lando and Mak 1991, Bolton 1996).

Rice is the staple food for these households and the most important crop, considering food security. FAO (1994) estimates that rice represents 75% of nutrition intake on average, with per capita consumption needs estimated at 151 kg of white rice or 250 kg of paddy, or 1.4 t per average household annually (MAFF 1996). This figure does not include rice requirements for seed, for compensating for postharvest losses, and for basic social and ceremonial purposes, which might easily amount to a further 500 kg of paddy yr^{-1}. Garden and other field crops and wild plants also contribute to the diet, but precise quantities are difficult to measure. The major source of protein in Cambodia is fish supplemented by smaller quantities of poultry, pork, and beef.

The vast majority of Cambodian farm households have de facto ownership of their land. By 1993, official land survey and legal titling had completed less than 10% of land claims (FAO

1994). Average farm sizes vary across the country, depending on production system. In the most densely settled provinces near Phnom Penh, such as Kandal and Kampong Speu, farm sizes may average less than 1 ha. More typical farm sizes are in the range of 1.0-2.0 ha in southeastern provinces such as Takeo, Svay Rieng, and Prey Veng. In areas with low population densities such as the northwestern provinces, farm sizes may reach 2.0 or up to 4.0 ha (FAO 1994, 1996; Rickman et al 1995).

Rice production is one of the major labor tasks undertaken in rural households. In most cases, the rice crop is grown using manual labor with simple tools. Cattle or buffalo are the major source of power for plowing and harrowing. However, the use of agricultural machinery in rice production is spreading (Rickman et a1 1995). Several studies have been made of the amount of labor required to cultivate 1 ha of rice. Results indicate large variations between the amount of labor required among farm households. Total average person-days ha^{-1} have varied from 85 to 114 d (Tichit 1981, Rickman et al 1995). One study, which involved a resurvey of the same households during two seasons, found a mean of 100 person-days ha^{-1}, but the standard deviation of the sample was very high: SD=48 d (Pingali 1989).

More than 90% of the labor demand for rice production is concentrated in the 9-mo wet season from May to January, given the dominance of rainfed lowland production. Within this

Table 1.3 Economic model of rainfed lowland rice production in Cambodia, 1995.[a]

Item	Inputs		Traditional system		Improved system	
	Unit	Unit price	Quantity	Value	Quantity	Value
Revenue						
Paddy[b]	kg	368	1,300	478,400	2,000	736,000
Subtotal				478,400		736,000
cost						
Seed[b]	kg	368	80	29,440		
Improved seed[c]	kg	800	0		80	64,000
Fertilizer						
Urea[b]	kg	680	0		50	34,000
DAP[b]	kg	864	0		75	64,800
Manure	Carts	0	5	0	10	0
Labor						
Family	Person-days	0	110		120	
Hired	Person-days	3000			0	
Irrigation			0			
Hired draft power[d]		95,650	1	95,650	1	95,650
Equipment and materials[c]		25,800	1	25,800	1	25,800
Miscellaneous			0			
Subtotal				150,890		284,250
Net revenue				327,510		451,750
Return per person-day				2,977		3,764

[a]Assumptions of improved model (FAO 1994): fertilizer and improved seed as shown with minimum water control (supplementary irrigation or good crop/water conditions). Quantities based on FAO (1994). Prices and values in Cambodian riels. US$1 = 2500 riels. [b]FA0 (1995) unpubl. farm trial price data. [c]EstImate extrapolated from FAO 1993 data. [d]RIckman et al (1995).

season, labor demand is heavily compressed into short periods during transplanting (June-July) and during harvest (December-January) (Nesbitt and Phaloeun 1991). Households frequently experience labor shortages during these periods and they usually hire or exchange labor to meet these peak demands. Some spread in these labor peaks occurs on farms due to the cultivation of rice varieties of different durations (early, medium, or late duration).

Different cropping operations place different demands on men and women due to common divisions of labor at the farm level. Women make up 60-65% of the agricultural labor force. Land preparation and other heavier tasks are more often undertaken by men. Transplanting and general crop husbandry is mainly undertaken by women, and both men and women may be involved in tasks such as harvesting (Paris et al 1992). There are, however, many exceptions to these patterns according to differences in the availability of household labor.

The costs and returns of rainfed lowland and flood recession rice production systems, using existing and improved technologies, are summarized in Tables 1.3 and 1.4.

Rice produced in the existing rainfed lowland system is mainly used for consumption. In this situation, input costs are effectively the net expenses of staple food production. In existing flood recession systems, a surplus exists for sale on farms with average-sized households and a farm size of 1 or more ha. With improved technologies, rainfed lowland farms with average-sized households may also generate a surplus for sale.

Table 1.4 Economic model of flood recession rice production in Cambodia, 1995.[a]

Item	Inputs		Traditional system		Improved system	
	Unit	Unit price	Quantity	Value	Quantity	Value
Revenue						
Paddy[b]	kg	368	2,700	993,600	3,300	1,214,400
Subtotal				993,600		1,214,400
costs						
Seed[b]	kg	368	80	29,440		
Improved seed[c]	kg	800	0		80	64,000
Fertilizer						
Urea[b]	kg	680	50	34,000	100	68,000
DAP[b]	kg	864	0		0	64,800
Manure	Carts	0	5	0	10	0
Insecticide (Azodrin)	l	11,000??	0		1	11,000
Labor						
Family	Person-days	0	140		166	0
Hired	Person-days	3000	30	90,000	0	0
Irrigation		variable	1	66,000	1	116,000
Hired draft power[d]		50,000	1	50,000	1	50,000
Equipment and materials [c]		25,800	1	25,800	1	25,800
Miscellaneous			0			
Subtotal				295,240		399,600
Net revenue				698,360		814,800
Return per person-day				4,108		4,908

[a]Assumptions of improved model (FAO 1994). Quantities based on FAO (1994). Prices and values in Cambodian riels. US$1 = 2500 riels. [b] FAO (1995) unpubl. farm trial price data. [c] Estimate extrapolated from FAO 1993 data. [d] Rickman et al (1995).

Cited references

Bolton M. 1996. Report on exploratory survey of wild food usage by rural households in Svay Rieng Province. CIAP Monthly Report. Jan 1996. Phnom Penh: Cambodia-IRRI-Australia Project.

Cameron BJ. 1995. Rural credit in Cambodia. Australian Agricultural Assistance Programme, Ministry of Agriculture, Forestry, and Fisheries.

Cameron BJ, Twyford-Jones. 1995. Marketing and product development. Australian Agricultural Assistance Programme, Ministry of Agriculture, Forestry, and Fisheries.

Chandler DP, et al (eds.). 1988. Pol Pot plans the future: confidential leadership documents from Democratic Kampuchea, 1976-1977. Southeast Asia Studies Monograph Series No. 33. Yale University.

Chandler DP. 1993. A history of Cambodia. 2d ed. Boulder, Colorado: Westview Press.

Delvert J, 1961. Le Paysan Cambodgien. la Haye, Paris: Mouten Co.

Dennis JV Jr. 1979. Rice production in Kampuchea (preliminary draft). New York: Department of Rural Sociology, Cornell University. (mimeogr.)

[FAO] Food and Agriculture Organization. 1994a. Cambodia: agricultural development options review (Phase 1). Vol. 1. Sector review. Rome: FAO.

[FAO] Food and Agriculture Organization. 1994b. Agricultural development options review (Phase I) Annex 8. Economic analysis of major options. Rome: FAO.

[FAO] Food and Agriculture Organization. 1994c. Agricultural development options review (Phase 1). Annex 10. Human resources in Cambodian agriculture. Rome: FAO.

[FAO] Food and Agriculture Organization. 1994d. Agricultural development options review (Phase 1). Annex 1. Institutions of Cambodian agriculture. Rome: FAO.

[FAO] Food and Agriculture Organization. 1996. 1995 Rice crop pilot survey technical report. Phnom Penh: Ministry of Agriculture, Forestry, and Fisheries.

Frings V. 1993. The failure of agricultural collectivisation in the People's Republic of Kampuchea (1979-1989). Centre of Southeast Asian Studies Working Paper 80. Melbourne: Monash University.

Grunewald E 1992. Essai d'analyse historique de l'evolution de I'agriculture Cambodgienne. Phnom Penh: Groupe de recherche et d'echanges technologiques.

Grunewald F. 1982. A propos de lágriculture dans le Cambodge medieval. ASEMI, 1-4, Paris.

Helmers K, Bleakley R. 1996. Farm household economy survey. Phnom Penh: Cambodia-IRRI-Australia Project.

Hou Yuon. 1955. Solving rural problems: a socialist programme to safeguard the nation. Cited in: Kiernan B, Boua C (eds.). 1982. Peasants and politics in Kampuchea, 1942- 1981. London: Zed Press.

[IBRD] International Bank for Reconstruction and Development. 1970. Report of the Economic Mission to Cambodia- 1969. Vol I. Southeast Asia and Pacific Department, Washington, D.C.: IBRD.

[IBRD] International Bank for Reconstruction and Development. Bank. 1995a. Cambodia rehabilitation program: implementation and outlook. A World Bank report for the 1995 ICORC Conference. Southeast Asia and Pacific Department. Washington, D.C.: IBRD.

[IBRD] International Bank for Reconstruction and Development. 1995b. Agricultural productivity improvement: Department of Agronomy Component Preparatory Mission. Washington, D.C.: IBRD and Centre de cooperation internationale en recherche agronomique pour le developpement.

[ILO] International Labour Office. 1995. Jobs for peace: a program for action for Cambodia. Bangkok: ILO.

Kiernan B. 1985. How Pol Pot came to power. London: Verso.

Kernan B, Boua C (eds.). 1982. Peasants and politics in Kampuchea, 1942-1981. London: Zed Press.

Lando RP, Solieng Mak. 1991. Without any real advantage: a baseline survey of rainfed lowland rice culture in Cambodia. Baseline Survey Report No. 1. Phnom Penh: Cambodia-IRRI-Australia Project.

Munson FP, Martindale KW, McMorris DS, Parachini KE, Raiford WN, Townsend C. 1968. Area handbook for Cambodia. Washington, D.C.: U.S. Government Printing Office.

Nesbitt HJ, Phaloeun C. 1991. Physical, biological, and socioeconomic characteristics and research activities of farming systems at CARRDI in Cambodia. Proceedings of the Rainfed Lowland Rice Farming Systems Research Planning Meeting, 2-6 Aug 1991, Myanmar.

Mysliwiec E. 1988. Punishing the poor: the international isolation of Kampuchea. Oxford: OXFAM.

Osbourne M. 1969. The French presence in Cochinchina and Cambodia: rule and response (1859-1905). New York: Cornell University Press.

Osbourne M. 1979. Before Kampuchea: preludes to tragedy. London: Allen and Unwin.

Paris T, Mandac AM, Chin C, Say P. 1992. An assessment of the economic contributions of women in rice farming in Cambodia. Paper presented at the International Workshop on Gender Concerns in Rice Farming, 19-25 Oct 1992, Chiang Mai, Thailand.

Pijpers B. 1989. Kampuchea: undoing the legacy of Pol Pot's water control system. Trocaire, Dublin.

Pingali P. 1989. Farm household survey 1988 and 1989 in Takeo, Kampong Speu, and Svay Rieng. (unpubl. data). Phnom Penh: Cambodia-IRRI-Australia Project.

Prud ‘Homme R. 1969. L’économie du Cambodge. Paris: Presses Universitaires de France.

[RGOC] Royal Government of Cambodia. 1994. National programme to rehabilitate and develop Cambodia. Phnom Penh: RGOC.

Rickman JF, Meas Piseth, Om Sothy, Khiev Chan Theavy, Nhem Sokha. 1995. Farm mechanisation and crop production in Cambodia. CIAP Baseline Survey Report No 5. Phnom Penh: Cambodia-IRRI-Australia Project.

Shawcross W, 1979. Sideshow: Kissinger, Nixon, and the destruction of Cambodia. New York: Simon and Schuster.

Shawcross W. 1984. The quality of mercy: Cambodia, holocaust, and modern conscience. London: Andre Deutsch.

Thomas R. 1978. L’evolution economique du Cambodge 1900-1940 deuxieme partie, Ph D dissertation, l'universite de Paris VII.

Tichit L. 1981. L’agriculture au Cambodge. Lágence de cooperation culturelle et technique. Paris.

United Nations Population Fund. 1995. Cambodia: demographic profile. Phnom Penh: National Institute of Statistics of Cambodia, Ministry of Planning.

[UNDP/NIS] United Nations Development Programme/National Institute of Statistics. 1995. Report on the socio-economic survey of Cambodia 1993/94 (all rounds). Phnom Penh: UNDP/NIS.

Vickery M. 1984. Cambodia 1975-1982. Singapore: Southend Press.

Vickery M. 1986. Kampuchea: politics, economics and society. Boulder, Colorado: Lynne Rienner.

Whitaker DP, Heimann JM, MacDonald JE, Martindale KW, Shinn RS, Townsend C. 1973. Area handbook for the Khmer Republic (Cambodia). Washington, D.C.: U.S. Government Printing Office.

Topography, climate, and rice production

H. J. NESBITT

Topography

Cambodia is rimmed on three sides by mountains with the large central plain containing the Tonle Sap lake and river complex in the center. To the west and southwest are the Cardomen and Elephant mountains, the Dangrek mountains lie along the Thai border in the north, and the lower reaches of the Central Highlands of Vietnam are found in the east. The central plains are extremely flat, with an elevation difference of only 5-10 m between the southeastern portion of the country and the upper reaches of the lake in the northeast, a distance of more than 300 km (Plate 3). The plains are a result of long-term deposition originating from mountains within Cambodia and from sediments carried into the plain by the Mekong River (see Chapter 3 for details).

The Mekong River rises and falls approximately 9 m each year, the height of which is influenced by melting snow in the Himalayas and rainfall in China, Myanmar, north Vietnam, Lao PDR, and Thailand. In Cambodia, it passes through the provinces of Stung Treng, Kratie, and Kampong Cham until it converges with the Tonle Sap at Phnom Penh. When it reaches Phnom Penh, the water divides to flow down both the Mekong and Bassak rivers to Vietnam. As the river level rises, some water also flows back up in a northwesterly direction along the Tonle Sap River into the Great (Tonle Sap) Lake. The lake can expand tenfold in area to approximately 25,000 km^2 between the months of May and November. Receding water from the large reservoir flows primarily down the Bassak River and feeds many irrigation areas in the provinces of Kandal and Takeo.

At the beginning of the wet season, farmers who possess land suitable for deepwater rice (Fig. 1) plow their soil and broadcast rice seed. In ideal seasons, these crops receive sufficient local rainfall to allow 6 or more weeks of growth before mid-July. They are then at an advanced stage of maturity allowing them to elongate fast enough to keep pace with the rising floodwaters associated with the Mekong River. Some of these rices can grow 20-30 cm d^{-1} and grow up to 4 m long (see Chapter 5).

Flooding rivers also flow up hundreds of small rivers and channels connected to lakes and small ponds. The lakes are allowed to flood during the wet season and, as the main river begins to recede, the access ways are blocked off with barriers erected by farmers to retain the water for dry season crop production. Crops are planted along the edges of the flooded areas and, as the water recedes during the dry season, water is pumped back onto the crops where possible. A succession of crops follow the edge of the lakes or floodplains as the water recedes, hence the term "recession rice."

Heavy silt loads in the Mekong River assure annual fresh deposits of fertile soil over the deepwater and recession rice areas.

Rainfall

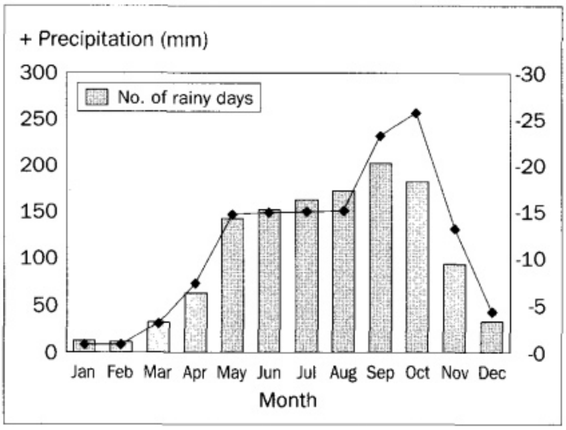


Figure 2.1 Monthly rainfall and number of rainy days. Phnom Penh.

Cambodia's topography also influences its rainfall distribution. Situated in the tropics, Cambodia experiences a monsoonal climate with distinct wet and dry seasons. Up to 4,000 mm of rain $annum^{-1}$ falls on the coastal areas southwest of the Dangkrek mountains and more than 2,500 mm $annum^{-1}$ is experienced toward the mountainous areas in the northeast part of the country (see rainfall map, p. 55). However, most of the rice-growing areas receive between 1,250 and 1,750 mm annually; the long-term distribution pattern is presented in Figure 2.1.

A 5-mo-long dry period between the last 2 wk of November and April of the following year allow rice crops to be harvested and stacked in the field while waiting to be transported or threshed in situ.

The first set of showers falling between March and May is locally known as the “mango washing rains” because blossoming trees are cleansed of the dry season dust buildup. These rains indicate the end of the dry season, and rice seedbed preparation begins. Rice stubble is also burned during this period.

By May, a majority of the rice soils are baked so hard that rainwater cannot easily penetrate. Several soakings are required before the soil is soft enough to be plowed by cattle or water buffalo. At the break of the season, when 100 mm or more of rainfall can be expected, deepwater (floating) rice farmers plow and broadcast their rice crops, and rainfed farmers complete their nursery preparation. Nurseries take up approximately 20% of the farm area.

Each year the rainfall pattern tends to have two peaks. In 1995, for example, the first rainfall peak was in May; it was April in 1984. The second peak in 1995 occurred in September and in 1984 in October. The average trend as shown in Figure 2.1 does not reflect the erratic nature of the rainfall. This irregularity is difficult to compensate for with innovative farming practices. On average, rain is expected on more than half of the days during the months of May through October. Mini-droughts often continue for 3 wk or more during any of these months and crops exposed to these vagaries suffer badly without some form of supplementary irrigation (Plate 4).

Heavy rains in September and October are essential for rice farmers. These flood the fields to a depth that will kill weeds but allow the rice to flower and set seed. Too much rain causes flooding in the lower fields and too little results in the crop running out of water before grain maturity.

The wet season in Cambodia generally stops abruptly some time in November and the fields dry quickly, thereby reducing the possibility of planting a second crop. Rice matures at different times over the next few months and is harvested by hand. The remaining rice stubble is grazed by cattle throughout the dry season.

Temperature

At the peak of the hot season (April-May), hot humid days reach Celsius temperatures in the mid-40s (Fig. 2.2). The evenings cool off by approximately 10 °C but remain warm and humid. Day temperatures are coolest in the months of October through January.

Warm dry days are required by rice farmers for grain drying while cool conditions are necessary for setting of some fruit and cultivation of many vegetables. Maturation into drying soil conditions also improves the quality of tobacco and other crops. Cooler temperatures at the end of the year are welcomed as farmers harvest and hand-thresh their rice during the day. Some palm sugar gatherers collect their extract in the heat of the day and thresh rice into the cool of the evening. These activities continue until February and March in some districts.

Humidity

The relative humidity in Cambodia fluctuates between 60 and 80% throughout the year (Fig. 2.3). The least humid days are experienced during the lead-up to the break of the wet season. Although the maximum daily humidity recordings remain reasonably constant, the difference between these and minimum humidity levels decreases considerably when rainfall is at its peak in September and October.

High humidity induces plant diseases and provides an ideal breeding environment for insects. However, it also reduces evaporation from water storage areas.

Evaporation and wind

Evaporation is closely related to temperature, humidity, and wind velocities. The line shown in Figure 2.4 illustrates that evaporation is greatest when maximum temperatures

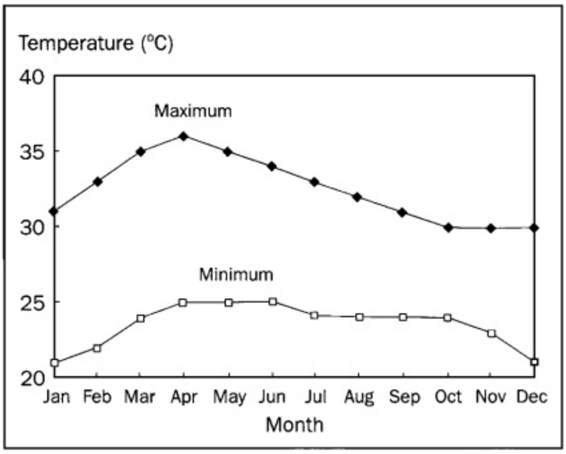


Figure 2.2 Monthly maximum and minimum temperatures. Phnom Penh.

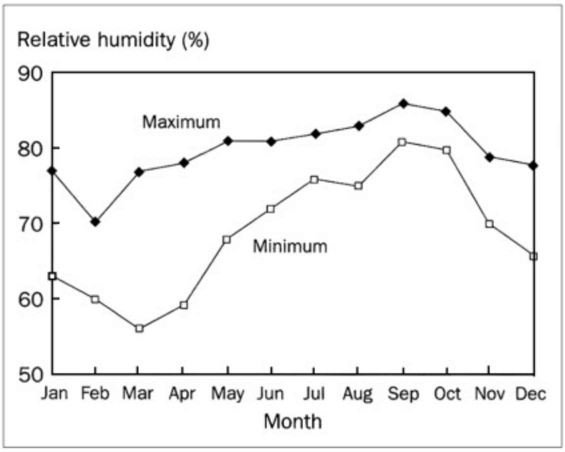


Figure 2.3 Relative humidity. Phnom Penh.

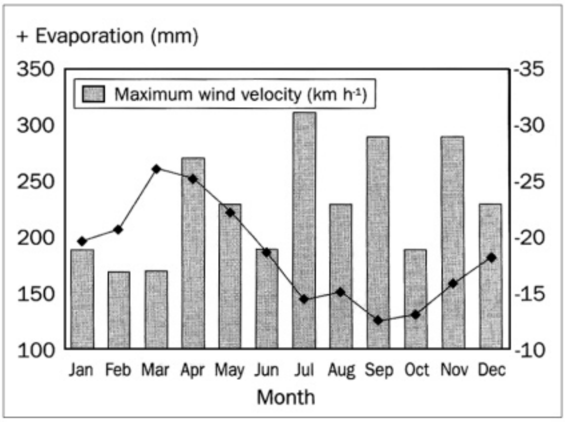


Figure 2.4 Evaporation and wind velocity. Phnom Penh.

are high and minimum humidity is at its lowest. At this time, water is evaporating from an open surface at a rate of more than 250 mm mo^{-1}. This loss is greater than the average precipitation for every single month of the year. Annual evaporation expected from a free standing surface is almost double that of the annual rainfall.

Evaporation in Cambodia is not related to seasonal winds as shown in the bars of Figure 2.4. These maximum wind measurements tend to be of momentary gusts, many of which precede rainstorms. Cambodia is not in the typhoon belt.

High evaporation and erratic rainfall during the early part of the year make it difficult for farmers to maintain reasonable levels of soil moisture for crop growth. The "mango rains" quickly dry and deep penetration of water into the soil comes only after a number of accumulated rainfalls.

Later in the year, when the number of rainy days increases (Fig. 2.1), cloud cover reduces the number of sunshine hours. Consequently, evaporation is reduced.

Daylength

Although Cambodia is situated between 10° and 15° north of the equator, it still experiences notable daylength changes. Figure 2.5 presents the number of hours including twilight that can be expected during the year. Being close to the equator, Phnom Penh receives only a short twilight of approximately 28 min. During the longest day of the year, on 21 Jun, there are about 13.2 h of daylight. On 21 Dec, the day is shorter by 1 h 40 min. The change in time also dramatically affects the flowering of a number of crops, the most important being rice.

Most traditional rice varieties flower at similar times each year. This is effectively a measurement of the number of days after the spring solstice (21 Sep) when the nights become longer than the days. The popular local rice known as Phcar Sla Thngun, for example, flowers on 11 Nov. Harvesting follows approximately 5 wk later, depending on the weather.

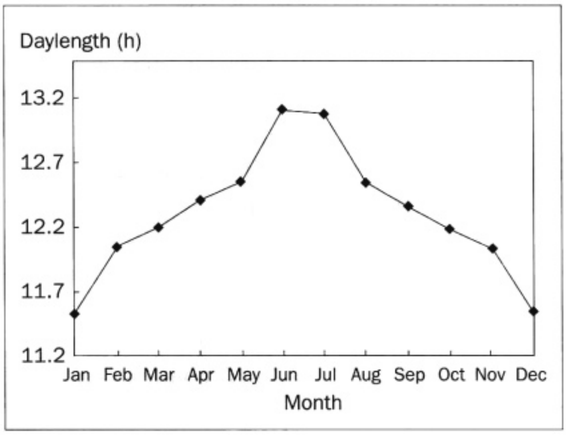


Figure 2.5 Monthly daylength means. Phnom Penh.

Sunshine hours

The number of sunshine hours experienced in 1 d controls plant growth by regulating the rate of photosynthesis. If the plant is well-watered and has good nutrition,

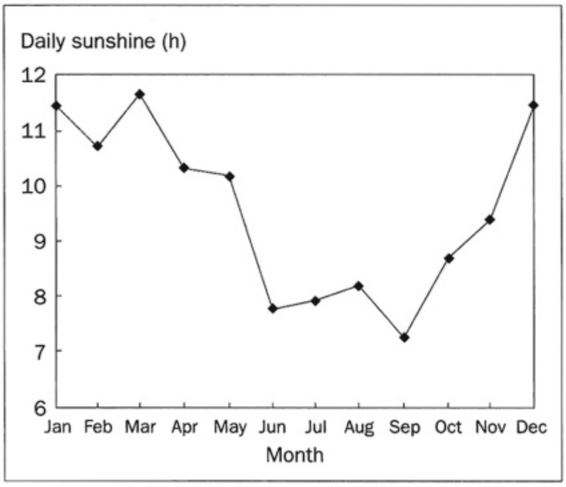


Figure 2.6 Monthly means of daily sunshine hours. Phnom Penh.

improving its exposure to solar radiation will increase the level of photosynthate assimilation. Solar radiation may be measured with a solarimeter or a Cambell Stokes-style sunshine meter. Measurements of sunshine hours collected over an 11-yr period from 1984 to 1995 are presented in Figure 2.6. They were highest in the period from December through February when most of the days were sunny. As the cloud cover increased through the wet season, the number of sunshine hours deceased. Potential crop yields are therefore higher in the dry season than in the wet season. Plants are also generally taller in the wet season and their growth duration is extended.

Cited references

[MAFF] Ministry of Agriculture, Forestry, and Fisheries. Various years. Phnom Penh, Cambodia: General Directorate of Hydrology and Meteorology, MAFF.

Sam Phallarsi M. 1973. Le quaternaire Cambogien—structure et stratigrafie. Ph D thesis, University of Paris. 182 p.

Soils and rice

P.F. WHITE, T. OBERTHUR, AND PHEAV SOVUTHY

A good understanding of the soil resources of the country is essential for improving the production and efficiency of Cambodian agriculture. The suitability of a wide range of cropping systems and management strategies will depend on the soil type occurring at any particular location (Plate 5). Unfortunately, there have been few studies on the soil resources of Cambodia. Apart from Crocker's exploratory survey of the soils of Cambodia in 1962, most studies have been commissioned on an ad hoc basis, producing databases of varying quality. Nevertheless, in recent years, the Cambodia-IRRI-Australia Project (CIAP) has made good progress in describing the general nature of the soils used for rice production. We now have a good understanding of the potential of the soils for intensified production and of the way these soils should be managed. Much work, however, is still needed.

This chapter describes our present knowledge on the soils used for rice production in the country. A brief account of the formation of the soils in relation to geology and landform is outlined first; a description of the characteristics of the main soils including the scope for management and improvement follows. The relationship between rice ecosystems and soil type is discussed in the last section. A more detailed and technical description can be found in White et al (1997), a manual for the recognition and management of Cambodian rice soils.

Geology and geomorphology of the ricelands

Geology

During the Paleozoic era, much of Cambodia's present rice-growing area was under the sea. During this time, calcareous sediments of marine origin formed in the sea bed. As the sea retreated during the Mesozoic era, the calcareous sediments were covered by colluvial and alluvial sediments deposited by rivers and through erosion of the surrounding sandstone mountains. Remnants of the marine limestone and calcareous sediments, however, can still be found in localized areas in Battambang, Kratie, and Kampot.

At the end of the Mesozoic era, acid granites and granodiorites formed intrusions. Later, particularly during the latter part of the Tertiary period, other acid, basic, and intermediate rocks such as rhyolites, diorites basalt, gabbro, and andesites were also extruded as eruptive veins in the existing rock. Patches of metamorphic schist, gneiss, and marble also occur in the southern part of the rice-growing areas (Lip et al 1960, Crocker 1962).

The Mekong River began to traverse Cambodia only in the relatively recent period. With the lowering of the land around the southern parts of Indochina, the river first appeared along the eastern edge of present-day Cambodia. With further geological movement and a rise in the southeast region of Vietnam and with the collapse of the marine gulf between Thailand and Cambodia, the river changed course flowing over the southwest of the country.

Geomorphology

Cambodia's rice-growing areas can be divided into three easily recognizable physiographic regions (Crocker 1962, Kawaguchi and Kyuma 1974, Tran Kim Thach 1385). White et al (1997) described these as:

- Old colluvial-alluvial plain. Soils occurring in these areas are developed from previously weathered material that has been transported and deposited at their current location. These areas form wide, slightly undulating plains which form the majority of Cambodia's rainfed rice-growing areas.
- Hills and valleys. Soils have developed in these areas through the process of decomposition of the underlying parent material. Most of the upland rice is grown in these areas.
- Active floodplains. Soils developed in these areas are pedologically young soils and receive annual deposits of fresh alluvium. Much of the irrigated and deepwater rice is grown on these soils. (See White et al [1997] for a more detailed description of these landforms.)

In general, soils formed in the same physiographic unit will have broadly similar properties, hence for purposes of this overview, the soils have been grouped according to where they have formed in the landscape. To better understand the soils occurring in Cambodian ricefields, a brief description of the morphology of the soils is given, followed by their chemical and physical properties. The soil types are listed in Table 3.1 and a summary of the available chemical data is given in Table 3.2.

Main soil types in the rice-growing areas

Soils of the alluvial and/or colluvial plains

Prey Khmer soils. The prominent feature of Prey Khmer soils is their deep sandy nature. They have a light-textured sandy surface layer extending deeper than 40 cm (but often more than 100 cm). The color of the surface soil is pale brown to very light gray with often a pinkish tinge. If a

Table 3.1 The major soils used for rice production in Cambodia and the proportion of rice area estimated to be occupied by each soil.

Landform/soil type	Proportion of rice area occupied (%)
Soils derived from alluvial and/or colluvial material	
Prey Khmer soil	11
Prateah Lang soil	28
Bakan soil	13
Koktrap soil	5
Toul Samroung soil	10
Soils developed from underlying parent material	
Labansiek soil	1
Kompong Siem soil	2
Soils of the active floodplains	
Kein Svay soil	2
Kbal Po soil	13
Krakor soil	15

Table 3.2 Chemical properties of the main rice soils in Cambodia.[a]

Property	Prey Khmer	Prateah Lang	Bakan	Koktrap	Toul Samroung	Kein Svay	Krakor and Kbal Po
pH (1:1 soil:water)	5.6	5.9	5.8	5.1	5.5	5.9	5.9
P sorbed (meq $100g^{-1}$)	na	44	135	210	390	na	330
Olsen P (ppm)	1.3	0.4	1.0	2.6	3.1	7.5	4.6
Organic C (%)	0.47	0.29	0.66	1.09	0.88	0.90	0.91
Total N (%)	0.05	0.03	0.06	0.11	0.09	0.10	0.10
CEC (meq 100 g^{-1})	1.8	1.3	6.3	6.7	18.2	12.6	13.5
Exchangeable Ca (meq 100 g^{-1})	0.38	0.84	2.33	0.42	7.81	6.67	7.78
Exchangeable Mg (meq 100 g^{-1})	0.12	0.25	0.68	0.16	4.31	2.79	3.05
Exchangeable K (meq 100 g^{-1})	0.02	0.03	0.07	0.06	0.16	0.18	0.19
Exchangeable Na (meq 100 g^{-1})	0.04	0.13	0.26	0.10	0.39	0.41	0.53
Electrical conductivity (dS m^{-1})	0.03	0.07	0.05	0.06	0.08	0.17	0.30

[a]Figures for the Prey Khmer, Koktrap, and Kein Svay are based on a limited number of samples. na=not available.

subsoil is present within the top 100 cm, it is a lighter color and contains a higher clay content than the overlying surface horizon.

These soils have no structure or hardpan development and few, if any, ironstone concretions. The small amount of clay in the surface soil is usually highly dispersed. The soils also have low water storage capacity and this makes them prone to drought.

These soils have very low cation exchange capacity, low organic matter, and low reserves of weatherable minerals but high rates of water infiltration. Water will generally penetrate and sit on top of an impermeable clay layer occurring deeper in the soil. Nutrients are therefore easily leached from these soils and fertilizers should be applied in frequent small doses. Responses to N, P, K, and sometimes S fertilizer application will occur. Glasshouse experiments have also shown the potential for Mg and B deficiencies. The soil pH is acidic but poorly buffered and is not a problem for flooded rice culture. There are difficulties in building up organic matter on these soils. Unfertilized rice yields on these soils range from about 600 to 900 kg ha^{-1} and farmers often apply sea salt as a fertilizer.

This soil type occupies about 11% of the rice area; it is found in all provinces.

Prateah Lang soil. Prateah Lang soils are characterized by a lighter textured topsoil overlying a heavier textured subsoil. The light surface soil is very light gray or pale brown and may have a pinkish tinge when dry. Plinthite development in the subsoil is usually a prominent feature of this soil. The soil makes up a substantial part of the old colluvial- alluvial terraces with the soil occurring in the upper fields generally having a sandier topsoil than soil occurring in the lower fields.

The effective rooting depth of this group is often restricted by a firm to extremely hard traffic pan occurring within the top 15-25 cm. The shallow soil volume and the poor water-holding capacity make this soil prone to drought. The topsoil is also usually structureless and the small amount of clay in this horizon is highly dispersed which generally causes a thin layer of clay to be deposited on the soil surface when it dries. The soil must therefore be very wet before it can be plowed by animal traction. The soil particles also settle quickly after being disturbed, and transplanting must occur within a few hours of harrowing. Ironstone gravel can occur throughout the profile and, in some cases, large ironstone boulders can outcrop the surface.

These soils have very low cation exchange capacity, low organic matter content, and low reserves of weatherable minerals. Unfertilized rice yields on these soils range from about 800 to 1400 kg ha^{-1}. Responses to N, P and K fertilizer application occur frequently and some areas are responsive to S application. Boron deficiency has also been observed with these soils in the glasshouse. The soil pH is generally acidic but it is not a problem for flooded rice production. Crops grown on this soil type, which occur in low areas and receive runoff from surrounding land having soils with higher Fe, exhibit iron toxicity symptoms. A very small area of this soil type may suffer from salt toxicity problems.

The soil occupies about 28% of the rice area and is found in all provinces.

Bakan soil. Characterized by a medium-textured gray to light gray topsoil over a mottled somewhat heavier subsoil (which usually has plinthite and/or ironstone), Bakan soils occur in the lower fields and depressions of the old colluvial-alluvial plains.

A blocky or sometimes massive structure in the surface layer is typical for this soil and the clay is usually highly dispersed with the surface becoming extremely hard when dry. Narrow surface cracks which do not penetrate deeper than 1-2 cm sometimes occur in the surface. The water-holding capacity of this soil is good, although soil volume is restricted by a firm traffic pan which usually develops within the top 15-25 cm of the soil and drainage is poor.

Clay mineralogy is mostly kaolinitic and hence, the soil has low cation exchange capacity. Fertility and organic matter levels are also low but this soil is generally more fertile than the Prey Khmer or Prateah Lang soils. The soil may receive runoff and some nutrients from the surrounding upper fields. Good responses to application of N and P fertilizers regularly occur. Responses to K and sometimes S fertilizers are also likely, especially if the area is used for intensive crop production at high N and P input levels. Unfertilized yields usually range from 1000 to 1800 kg ha^{-1}. The soil is usually acidic and Fe toxicity problems may occur in some areas although the problem is not widespread.

The soil occupies about 13% of the rice area and is found in all provinces.

Koktrap soil. A dark gray to black heavy-textured topsoil over a lighter gray, clayey subsoil gives the Koktrap soil group its distinctive appearance. The topsoil usually extends only 15-20 cm deep and there is a sharp boundary to the lighter colored subsoil. The subsoil usually has abundant red and orange mottles. Areas where these soils are found were possibly former tidal lands, the soils originally being formed under swampy conditions. Soils in this group have been mistaken as acid sulfate soils by some researchers. If these soils were once acid sulfate soils, they have been subsequently leached of much of their acidic and sulfuric materials. These soils occur only in rainfed areas and do not receive fresh annual alluvial deposits.

The surface of this soil is well-structured and large cracks form on drying. The soil has good water-holding characteristics but the soil volume is restricted by a plow pan which develops in the 20-25 cm surface. In some areas the soil remains soft after plowing and harrowing; transplanting must then be delayed by 1-2 d.

The soil has moderate cation exchange capacity and organic matter content although the organic matter appears very stable and contributes few nutrients through mineralization. Total P levels in the soil are very low. Without fertilizer application, yields on this soil type are very poor (400-800 kg ha^{-1}). However, excellent responses to N, P, and K fertilizer application occur. Care must be taken to apply P as well as N fertilizer; N application alone results in reduced yields and can kill the crop. Symptoms of Fe and possibly Mn toxicities frequently occur on these soils. Soil pH is moderately acidic and strongly buffered. The soil pH does not rise substantially after inundation of this soil, possibly causing problems for plant growth.

This soil type occupies 5% of the rice area and occurs mainly in Svay Rieng, Prey Veng, and parts of Takeo.

Toul Samroung soil. A brown or gray, cracking, heavy textured topsoil about 30 cm deep over a gleyic, grayish brown, heavy-textured subsoil represents the characteristic profile of the Toul Samroung soil group. This soil is primarily found on the slightly undulating plains formed from alluvium and colluvium of mixed origin; mainly basic (basalts) and partly acidic rocks (granite, sandstone, and shale) washed from surrounding hills and mountains. In some cases, the soil receives local alluvium deposited through minor creeks and rivers.

The surface soil, when dry, is usually very hard and has a large blocky structure. Large cracks develop which penetrate deep into the soil when it dries. The water-holding capacity of the soil is good although drainage through the profile is poor. A hardpan generally develops within the top 20-25 cm of the soil.

Soil fertility, nutrient-holding capacity, and nutrient reserves within the soil are moderate; responses only occur to application of P and N fertilizers. After an extended period of intensive production with high levels of N and P application, responses to K fertilizer application may also be expected in some areas, particularly on the gray phase of this soil. Unfertilized rice yields on these soils range from about 1400 to 2000 kg ha^{-1}. The pH of the soil is usually slightly acidic to neutral and does not pose a problem for crop production.

The soil occupies about 10% of the rice area and is found mainly in Battambang, Banteay Meanchey, Pursat, Kampong Thom, Kampong Cham, and Kampong Speu.

Soils developed from underlying parent material

Labansiek soil. The deep, uniform, granular-structured red to reddish brown profile gives Labansiek soils their characteristic appearance. The texture is mainly clayey throughout but may have a slightly sandy feel because of the stable microstructure of the mainly kaolinitic clays and iron and aluminum oxides and hydroxides. These soils have formed on the undulating sloping lands on the sides of hills representing the sides of ancient volcanoes. The parent material of this soil is mainly basaltic rock.

The soils are well-structured with good water-holding capacity. They can be very sticky and difficult to plow if worked at too high a moisture content. A large petroferric hardpan can develop and outcrop the soil surface in some areas which have been puddled for flooded rice cultivation for an extended period.

These soils have been quite strongly weathered and have moderate to low cation exchange capacity, organic matter content, and reserves of weatherable minerals. The pH is slightly acidic to neutral. Good responses to N and P fertilizers occur on these soils and responses to K application would be expected in areas used for intensive crop production receiving high levels of N and P Unfertilized rice yields of about 1400-1600 kg ha^{-1} may be expected from these soils.

This soil is found in Kampong Cham, Kratie, Mondulkiri, Ratanakiri, and Battambang. It occupies about 1% of the rice area which is almost exclusively upland rice. These soils are used mainly for rubber and horticultural plants.

Kompong Siem soil. The Kompong Siem soil group is best described as a black or dark gray or very dark brown, cracking, sticky clay. The soil surface is very plastic and sticky when wet and retains its very dark color even when dry. This soil is found mainly in a sequence with the red Labansiek soils; the Labansiek soils occupy the hill slopes while the Kompong Siem soils form the adjacent lower slopes and valleys. The soil is mostly formed from the underlying limestone or basalt parent materials and from colluvial and alluvial outwash from the surrounding upper slopes. In some areas, the soil profile is shallow (only about 1 m) with abundant gravel and some large basalt boulders on the surface of the soil.

The soil is very difficult to work when it becomes too wet. Land preparation must therefore occur early, before too much rain falls, although wetting of the soil is initially slow. The soil has a high water-holding capacity, but the available water content is limited because of strong water retention capacity. Deep cracks form in the soil when it dries.

This soil group is one of the most fertile in Cambodia. Responses to N and sometimes P fertilizer (but not to other nutrient) application occur. The calcimorphic (those formed on limestone) Kompong Siem soils are neutral to alkaline while the basaltic (those formed on basalt) Kompong Siem soils are neutral to acidic. Zinc deficiency problems may occur in the calcimorphic soils while Fe toxicity may be present in basaltic soils which remain inundated for extended periods. Unfertilized yields of more than 2000-2500 kg ha^{-1} can be expected.

This soil type occupies less than 2% of the rice area and occurs mainly in Battambang, Kampong Cham, and Kratie.

Soils developed on recent alluvium

Kein Svay soil. Formed on the river levees and backslopes, Kein Svay soil is a deep, weakly developed, brown, medium to heavy-textured soil. The subsoil is similar to the surface horizon but may be grayer in some area. The backslopes where most of the rice is cultivated are usually flooded each year, receiving fresh alluvium, whereas the levee crests are inundated for only short periods, if at all.

Soil texture ranges from sandy loam on the levee crests to clay or clay loam near the bottom of the backslopes. These soils generally have a good friable structure, but in some areas, the surface soil may have a hard and blocky structure after continuous puddling for rice cultivation. The soils on the lower backslopes form large deep cracks when they dry.

These are fertile soils with good cation exchange capacity and moderate organic matter level. The soils have few limitations for rice production. Responses to only N fertilizer application occur. Unfertilized yields range from 1800 to 2600 kg ha^{-1}.

This soil occupies less than 2% of the rice area and occurs mainly along the Mekong and other major rivers in Cambodia.

Kbal Po and Krakor soils. The Kbal Po and Krakor soils are characterized by a gray, brown, dark gray or black, cracking, heavy-textured topsoil over a lighter colored heavy-textured subsoil. The soils in this group are young and poorly differentiated; the only difference between the subsoil and the topsoil generally being the lighter color. The soils in this group are formed from fresh alluvium deposited by floodwaters each year. The soils generally remain flooded for about 3-5 mo each year. The depth of the darker upper layer of the soil varies and increases from about 20 cm to more than 100 cm with increasing distance along the edge of the floodplain to the area of permanent water.

The soils are well-structured with good water-holding capacity. The subsoil generally remains moist throughout the year. These soils are easy to work but may be too soft in some areas where the water content is high; timeliness of land preparation is thus essential in the wet season and good water control is needed in the dry season.

These are fertile soils with a high to moderate cation exchange capacity and organic matter content. The fertility is renewed each year by the deposition of fresh alluvium. Fertility also tends to be higher in areas closer to permanent water. Close to the water, responses to N fertilizer application only are expected, whereas on the fringes of the floodplains, responses to both N and P fertilizer application may be expected. In some areas of the active floodplains near the border with Vietnam, the soil may be acidic. In these areas, the soils are potentially acid sulfate soils. Deep plowing may bring acid to the surface, creating problems for rice production. These problems can be avoided by shallow plowing in these areas. Unfertilized rice yields on the Kbal Po and Krakor soils range from about 1800 to 2600 kg ha^{-1}.

This soil occupies about 30% of the rice area, occurring mainly in the provinces surrounding the Tonle Sap and in the southern provinces of Takeo, Prey Veng, Svay Rieng, and Kandal.

Relationship between rice ecosystem and soil type

Rainfed lowland rice

Rainfed lowland rice can be found growing on all soil types except the Labansiek soils (Table 3.3). The major part of the rainfed lowland rice crop, however, is grown on the soils of the colluvial-alluvial plains. Medium- and short-duration rices are generally grown on the lighter textured soils (Prey Khmer and Prateah Lang soils) occurring on the medium and upper fields, while the late-duration varieties are more often grown in the lower fields. The soils in the lower fields tend to be heavier textured soils (Bakan, Toul Samroung, and Koktrap soils), although the sandier soil types may also be found in the lower fields.

Table 3.3 Proportion (%) of each of the main rice ecosystems in Cambodia occupied by different soil types.

Landform/soil type	Shallow water, wet season	Deepwater	Irrigated	Upland
Prey Khmer	13	3	4	18
Prateah Lang	30	0	10	37
Bakan	13	15	6	0
Koktrap	5	5	1	0
Toul Samroung	15	5	13	16
Labansiek	1	0	0	18
Kompong Siem	2	0	2	9
Kein Svay	0	5	11	0
Kbal Po	14	21	47	0
Krakor	7	46	6	0

Table 3.4 Proportion (%) of each rice ecosystem falling into high-, medium-, or low-potential soils.

Soil potential	Shallow water, wet season	Deepwater	Irrigated	Upland
Low[a]	56	18	20	55
Medium[b]	21	10	14	34
High[c]	23	72	66	8

[a]Low-potential soils have chemical or physical limitations that are difficult to overcome through management, e.g.. low cation exchange capacities or Fe toxicity problems. Soils in this category are Prey Khmer, Prateah Lang, and Bakan soils. [b]Medium-potential soils have chemical or physical problems that can be corrected through management, e.g., K deficiency, poor physical structure. Soils in this category are Koktrap, Toul Samroung, and Labansiek soils. [c]High-potential soils have few limitations to rice yields. Soils in this category are Kompong Siem, Kein Svay, Kbal Po, and Krakor soils.

More than half of rainfed lowland rice is grown on soil which can be considered of low potential. The low-potential soils have chemical or physical constraints which are difficult to overcome through management and hence are likely to restrict yield. The high-potential soils which have few soil-related constraints grow an estimated 20% of the rainfed lowland rice crop (Table 3.4).

Deepwater rice

Most of the deepwater rice is grown on soils that developed from recent alluvium with close to 50% of the rice grown on the fertile Krakor soils. A good amount of deepwater rice is also grown on Kbal Po soils and a small proportion is grown on Bakan, Koktrap, or Toul Samroung soils located in very low parts of the landscape such as those around small lakes or in channels. The nature of the deepwater rice ecosystem suggests that a vast majority of deepwater rice is grown on soils of high potential.

Irrigated rice

Irrigated rice can be found on any soil type as long as water is available. Most rice, however, is grown on the Kbal Po soils and the Kein Svay soils. This includes rice grown as recession rice as well as that grown under full irrigation. Indeed all the recession rice (rice receiving supplementary irrigation) is grown on the Kbal Po or Krakor soils. A few small irrigation schemes exist on the Prateah Lang, Bakan, and Toul Samroung soils.

Most of the irrigated rice is grown on soils of high potential. This proportion is likely to increase in the medium term as high-potential soils offer the best return on investment used to build irrigation structures. The area of irrigated rice grown on the other soil types is also likely to increase, particularly in the long term, as the area of irrigated rice expands.

Upland rice

Upland rice is found primarily on the Prateah Lang soils and the Labansiek soils of the hills. Small areas of upland rice may also occur on the colluvial/alluvial plain soils and the Kampong Siem soils.

Most of the upland rice is grown as part of the slash-and-burn shifting cultivation of the forested areas, but a proportion is also grown in the lowland rice areas on slightly raised locations which do not become inundated with water during the wet season.

Cited references

Brinkmann R. 1970. Ferrolysis, a hydromorphic soil forming process. Geoderma 3:199-206.

Crocker CD. 1962. The general soil map of the Kingdom of Cambodia and the exploratory survey of the soils of Cambodia. Phnom Penh, Cambodia: Royal Cambodian Government Soil Commission/United States Agency for International Development.

Ho Tong Lip, Siteck EA, Litzenburger SC. 1960. Results of soil fertility studies with lowland rice in Cambodia. Trans. 7th Int. Congr. Soil Sci. 3:276-284.

Kawaguchi K, Kyuma K. 1974. Paddy soils in tropical Asia. Part 1. Description of fertility characteristics. Southeast Asian Stud. 12:3-24.

Tran Kim Thach. 1985. Pedogeomorphological map 1:500,000 of the People's Republic of Kampuchea and explanatory report[in French]. Ho Chi Minh City, Vietnam: Sub-national Institute of Planning and Projection

White PF, Oberthur T, Pheav Sovuthy. 1997. Soils used for rice production in Cambodia. A manual for their recognition and management. Manila (Philippines): International Rice Research Institute.

Rice-based farming systems

H.J. NESBITT AND CHAN PHALOEUN

Rice is primarily cultivated on land which is flat and easy to bund for rainfed water conservation or for irrigation. Suitable sites are concentrated around the Tonle Sap Lake and toward the southeast (see rice area map on p. 55). The total area mapped for rice-based farming systems encompasses 3.2 million ha but this includes cropped areas, previously cropped fields, roads, villages, and some nonarable land (Bruce 1992). Grazing and upland crop areas are located within and immediately adjacent to these mapped sites. Upland rice and very small areas of bunded rice are also found scattered throughout the rolling hills in the north and northeastern provinces of Preah Vihear, Stung Treng, Kratie, Ratanakiri, and Mondulkiri. Government statistics indicate that rice production is small in these areas.

Upland rice is cultivated on sloping land without bunds to retain water. In the north and northeastern provinces, it is often sown within a mixed cropping system by farmers who practice slash-and-burn agriculture. Multicropping includes pearl millet, mungbean, maize, cassava, sweet potato, and many other crops. Pure stands are regularly found throughout the country. In Kampong Cham, these are occasionally rotated with upland crops such as mungbean or soybean. Fertilizers are not included in the system and rotations are usually on a 3-4-yr basis.

Rainfed lowland farmers bund fields on the flat plains to retain water for weed control and for crop growth during dry periods. At the peak of the wet season, when the plains are flooded, surface drainage and internal drainage are very restricted or they cease. Field size is often related to soil fertility, land gradient, and population density. Close to Phnom Penh, fields on alluvial soils may be 20 m^2 or less, while in Prey Veng they are usually 1 ha or greater.

Flat areas are also preferred for irrigated rice production. Many of the irrigated areas under recession rice are flooded in the wet season and receive supplementary irrigation in the dry season.

Deepwater rice-based systems are located along the rivers and edges of the Great Lake complex. As mentioned in Chapter 2, the river level rises in May or June, flows back up the Tonle Sap River and floods deepwater rice-growing farmland. The water may rise and fall a number of times during the season, depending on snow melts and rainfall in the river catchment areas. Height, frequency, and duration of flooding are unpredictable. For these reasons, deep-water rice cultivation has decreased dramatically in recent years (Table 5.1).

Details of rice cultivation techniques for all ecosystems may be found in Chapter 5.

Farming systems and rainfall

Cambodia's climate and its effect on rice-based farming systems is briefly described in Chapter 2. As mentioned, most rice areas are located in the 1,250-1,750-mm rainfall range. This is sufficient for excellent crop yields if the rain falls in a consistent pattern. However, the unpredictable nature of the rainfall severely restricts both the potential for significant rice yields and the patterns for farming diversity. Opening rains are often delayed and can be followed by dry periods of 3 wk or more. Heavy falls on the impermeable soils cause waterlogging, damaging prerice cash crops.

Farmers' preference for photoperiod-sensitive varieties is in response to the irregular rainfall pattern. These varieties commence their reproductive stages at predetermined daylengths and for this reason, transplanting can be delayed for up to 5 mo after sowing.

An abrupt end to the season reduces any potential for postrice crop cultivation because the effective rooting depth of the soils is shallow and the water-holding capacity is limited, hence the soils dry very quickly. In addition, an unpredictable early end to the rains encourage farmers to diversify their range of varieties by maturity, thereby limiting the potential for high yields.

Farming systems and soils

A majority of the Cambodian rice-growing soils have impermeable subsoils with poor internal drainage. The soils also flood easily after monsoonal rains. Cultivation of upland crops within the same fields require drainage and, for this reason, most of these crops are grown on nonrice fields. For example, maize, sugar cane, tobacco, and sesame are generally grown on the levee banks of major rivers. Sesame is sometimes grown prior to rice in fertile deepwater rice areas and sugar cane plus tobacco are cultivated in very small patches close to the farm house. Groundnuts are found in well-drained sandy soils in the upper fields. These soils have tremendous potential for nonrice crops to be grown in the dry season under irrigation.

Mungbean and soybean are generally cultivated in reasonably fertile sloping soils on the fringes of the ricefields in Kampong Cham. Very small areas are also planted by rice farmers for home consumption in most provinces.

Where possible, farmers improve their soils with application of farmyard manure (Plate 6). An average farm household possesses only 3-4 animals and two-thirds of the manure is applied to the nursery (Lando and Solieng 1994a,b,c). Therefore, the remaining cropped area receives little nutrient application and crop yields are consequently low. Research has shown that it is possible to improve rice yields by 40% in Cambodia (CIAP 1993) by growing green manure crops beforehand. Farmers who participated in the research scheme were enthusiastic about the technology. However, seed supply and other problems have constrained adoption.

Low fertility severely limits rice yields on most soils each year. Small areas of acid sulfate, saline, and iron toxic soils also exist and some local varieties adapted to these conditions can be found in these ecosystems.

Most of the inorganic fertilizers imported into Cambodia are applied to irrigated rice crops, vegetables, and cash crops. The small amount applied to rainfed rice is usually in the form of a root-dipping solution made with cow manure and fertilizer or as a topdressing. Good nutrient management practices and fertilizer recommendations for each soil type are being developed by CIAP

Cropping systems

Rice-based cropping systems predominate in the rainfed lowlands (Plate 7). Within this ecosystem, the varieties may be classified as being either early- (presently 16% of the rice-growing area), medium- (33%), or late-maturing (36%) varieties. They are categorized on the basis of flowering date. Early-maturing varieties flower before 15 Oct, medium-maturing ones between 16 Oct and 15 Nov, and late-maturing varieties afterward. Most of the medium- and almost all late-maturing traditional varieties are photoperiod-sensitive (Plate 8). Consequently, soil management practices need to be adjusted accordingly. In addition, more farmers grow more early-maturing varieties, most of which are nonphotoperiod-sensitive modern varieties. Better water control will improve the health of these crops and there is great potential for a significant increase in grain yield with balanced fertilizer application.

Early-, medium-, and late-maturing varieties are located in the upper, medium, and lower fields, respectively, to match the maximum experienced water depth (Fig. 4.1).

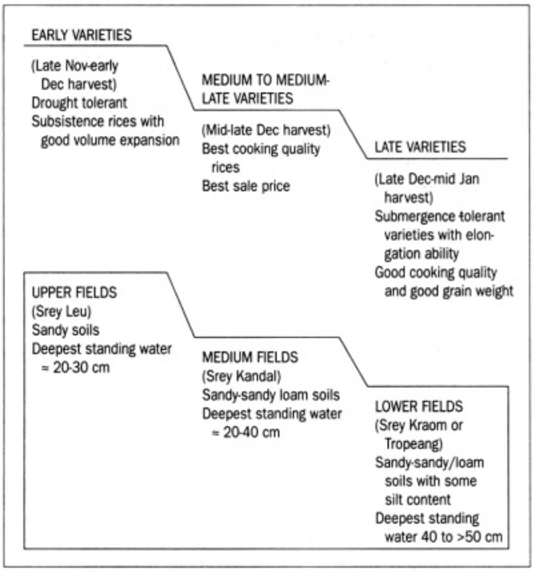


Figure 4.1 Typical characteristics of rainfed lowland rice varieties to best suited field level.

In general, the soils are also different, with sand content of the A horizons decreasing and silt content increasing from the upper to the lower fields. These conditions lead to differences in grain quality of traditional rices.

Deepwater rices mature after late-maturing rainfed varieties and are harvested in January or February of the following year. The soils in these fields are usually more fertile than those in the rainfed lowlands and no fertilizers are applied.

Irrigated (wet and dry season) rices are nonphotoperiod-sensitive and short in duration. A considerable increase in grain yield is expected with improved fertilizer application.

Land preparation in rainfed lowland and deepwater ricefields begin at the break of the wet season (Fig. 4.2). This may be as early as April or May. Deepwater rice seed is broadcast simultaneously to allow sufficient time for the plants to reach physiological maturity prior to flooding from the rising rivers. In the rainfed areas, nursery preparation begins soon after and transplanting starts when the soils are sufficiently soft to plow and/or puddle. Harvest dates are followed according to maturity classification.

As previously mentioned, the area of cultivated upland crops in Cambodia is quite small but a large number of cropping system variations exist. Apart from vegetables, very small areas of nonrice crops generally are fully irrigated. Maize is grown under rainfed conditions on fertile soils along rivers. They are planted at the beginning of the wet season rains and harvested prior to the September floods. These soils are replenished with fresh deposits of silt on an annual basis. There is generally insufficient time to plant a crop of rice after harvest and intercropping is not a common practice. Tobacco is grown on similar soils (but on higher locations) at the end of the rains and mature into dry conditions. Some farmers also plant vegetables on these soils beforehand. Sesame is grown under similar conditions and, because of its short growth duration, is often double-cropped in deepwater rice areas. Soybean and mungbean are cultivated on hill sides, with the crops being alternated from year to year. These sites are generally not double-cropped.

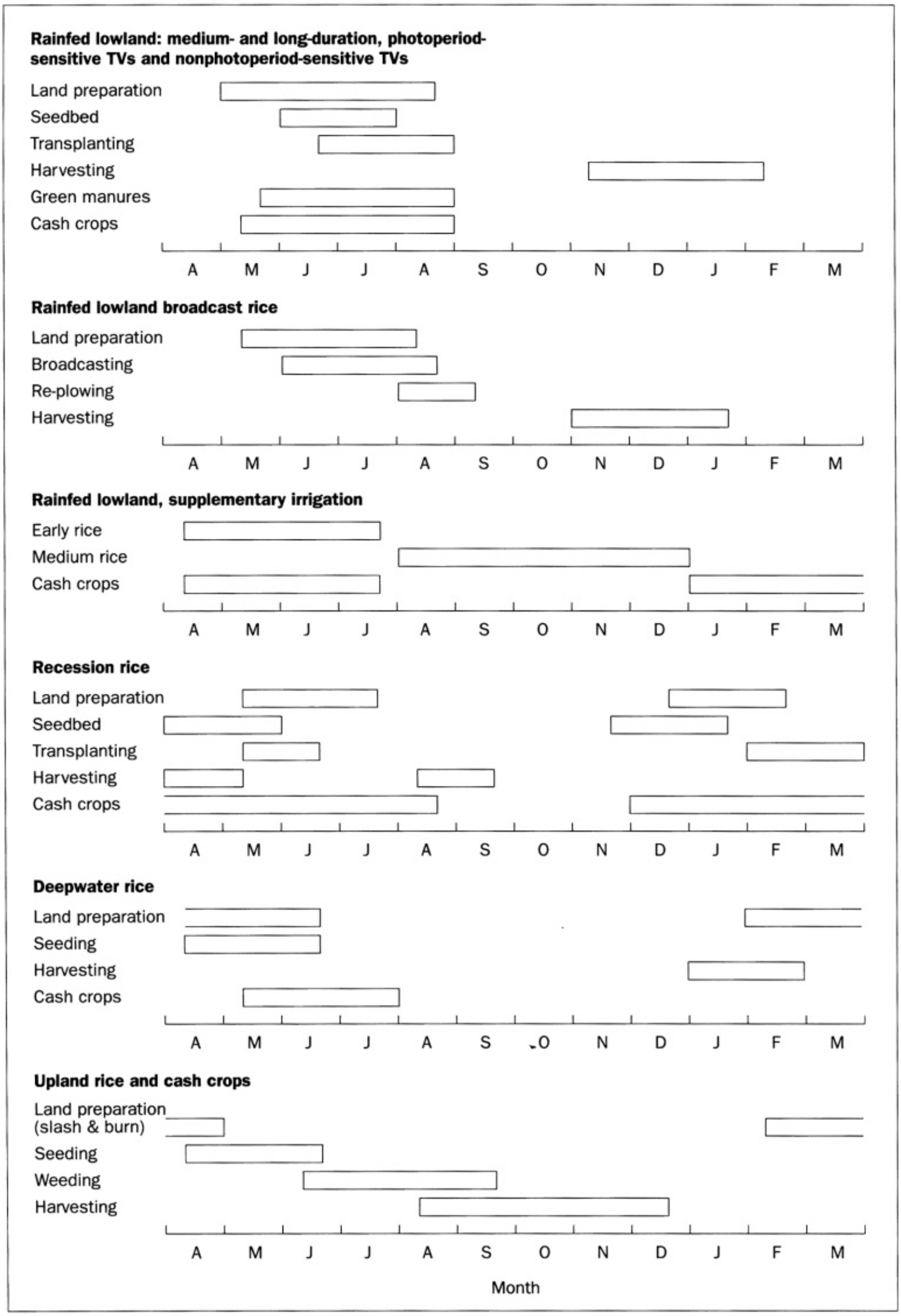


Figure 4.2 Rice sequences by agroecosystem.

Double cropping of rice with cash crops often follow the sequences presented in Figure 4.2. Prerice crops predominate because the wet season usually comes to an abrupt end and the soils have poor water-holding capacities. They must be sited on well-drained soils or hilled for improved drainage. Only short-duration crops are cultivated successfully without supplementary irrigation in this ecosystem.

Rice cultivation practices

Rice farming practices vary considerably between the rainfed lowland, upland, deepwater, and irrigated areas. Farmers in the rainfed lowland ecosystems start to apply farmyard manure to their fields in April and May of each year. In the event of a shortage, preference is given to fields cultivated as seedling nurseries to soften the soil for plowing and to improve seedling viability. Depending on availability, application rates vary from 200-300 kg to 25 t farmyard manure ha^{-1} of nursery (Lando and Solieng 1994a).

When there is sufficient rain to prepare the nursery, the soil is plowed twice and harrowed once or twice to level the plot. A furrow is plowed diagonally across the field to improve drainage. The prepared nursery is immediately broadcast with presoaked (24-36 h) rice seed. Broadcast rates vary from 50 to 70 kg per 0.1 ha of nursery, depending on the soil's fertility. Nurseries occupy 15-25% of the total farm area and are preferably located close to a water supply for supplementary watering during the year and are often located near the farmer’s house.

Main field plowing may immediately follow nursery bed establishment by 1-3 mo depending on the rainfall pattern. Preference is given to fields with free standing water for ease of transplanting. Many soils compact easily, and in these cases, sufficient land is plowed for 1 d of transplanting only. The process of transplanting varies considerably. Some farmers apply fertilizers basally, some dip the roots in a fertilizer/cow manure mixture; transplanting sticks may be necessary and transplanting densities range from 80 to 800,000 hills ha^{-1}. The recommended transplanting rate for modern varieties is at 250,000 hills ha^{-1}.

Broadcasting of rainfed rice is a common practice in Battambang and in some parts of Pursat and Banteay Meanchay. This is generally achieved by plowing the soil once or twice, broadcasting dry seed, and possibly harrowing once after sowing. Labor for establishing and managing a nursery plus transplanting is thereby eliminated. Weeds are a problem using this technique and often farmers will plow the crop once 6-8 wk after emergence to kill the weeds. The rice is tall enough to be partially turned in but sufficiently mature for roots to develop from the first node on the culm. The plant can then continue to grow to maturity.

Spot weeding of rainfed fields is a common practice and farmers regularly drain or rebund their fields during the wet season for improved weed control. Harvesting is done using a hand-held sickle and sheaths are regularly stacked on bunds to dry prior to threshing. Once dried, the sheaths are generally carted or carried to the farm house and threshed at leisure over the dry season. Grain is stored permanently in aboveground silos or in temporary granaries prior to sale. The rice straw is heaped in a pile (usually around a post) to be fed to animals during the wet season when there is little pasture to graze.

After harvest, the stubble is grazed by cattle and other animals. They may be tethered or free-range-fed under the eye of a herd boy. Some farmers burn the stubble during the first quarter of the year to aid land preparation and kill residing pests and diseases. This practice decreases the quantity of roughage for grazing animals. At the onset of the first rains, germinating weeds increase the availability of green feed in rainfed and deepwater ricefields. Reasonable quality legume pasture also develops on the bunds and other ground not flooded in the wet season. There is potential for improving this pasture as a source of animal feed with the application of P and introduction of improved species (P. White, CIAP, pers. commun.). As transplanting progresses and the land available for grazing diminishes, cattle are often taken to upland sites to feed or are fed by hand near the house. Freshly cut material is supplemented with straw collected after threshing.

Upland rice is usually dibbled into the ground with the assistance of a sharp stick after the area has been prepared by slashing and burning existing forest cover. Sowing follows early-season rains and harvesting is in October or November. Fertilizer is not applied. Crops may be pure stands or intercropped with maize, cassava, and beans. In subsequent crops, weeding may be necessary.

Preparation of land for deepwater rice starts immediately before the break of the wet season when farmers burn the previous year's stubble. Plowing follows immediately. The preferred practice is two plowings and one harrowing followed by broadcasting of dry seed at 120-150 kg ha^{-1}. However, if the rain is particularly late, some farmers may broadcast the rice seed and plow it in or broadcast it over single plowed soil. The fields are not bunded and weed incidence is prolific. Animals regularly graze the fields before flooding. Some farmers weed their fields but few apply herbicides or spray pesticides. Harvesting is conducted after the floodwaters recede. The stems are cut immediately below the panicle and the sheaths are returned to the village for threshing. Fertilizers are rarely applied to deepwater ricefields.

Most dry season rice is cultivated in flood recession areas. As such, it receives regular nutrient supplementation from siltation and fertilizer is applied in the form of urea as a top-dressing only, The first available fields are used as nurseries. From these, fields from succeeding recession areas are transplanted. Water is pumped back up the profile from rivers and recession ponds. Modern, nonphotoperiod-sensitive varieties are grown and recommended practices for these are followed. Transplanting is spread over the November to February period. In some areas, supplementary pump irrigation is provided to crops at the beginning of the wet season.

Rice-animal-fish interactions

Most farm households possess a small number of domestic animals. These include chickens, ducks, pigs, and cattle. Chickens and ducks are generally raised for egg and meat consumption while pigs and cattle provide a valuable source of cash income (Plate 9). Chickens, ducks, and pigs are reared on household scraps and rice bran as well as scavenging nearby the village.

Children are often responsible for tending the cattle. During the dry season, they drive them to ricefields, noncropped areas, and grassed roadsides. After transplanting, cut-and-carry techniques are more often employed to protect the crops from cattle breaking from their tethers. By this time, flooding has reduced the grazing area and rice straw is hand-fed to the animals as roughage.

At night, the animals are sheltered under the houses or in nearby sheds. Their manure is collected and applied to vegetable patches or rice nurseries and transplanting fields.

Cattle and water buffalo provide draft power for a majority of the farm households. Lando and Solieng (1994a,b,c) observed that although farmers owned an average of 3.4 animals, the distribution was uneven. In a survey of the rainfed lowland, 21% of farmers did not own draft animals (Rickman et al 1995). These farmers hired animals from neighbors resulting in delays in farming activities. Lower crop yields consequently result from badly timed practices.

Small pond fish farming has increased in popularity over recent years. However, only a small number of farmers have experimented with raising fish in the ricefields (see Chapter 8 for details). The procedure is to dig trenches around or through the fields. As the water level drops, the fish are able to retreat to deeper waters in the field. Control of predatory fish proves to be difficult and rainfed fields often dry out completely during the mini-droughts of the wet season. However, properly prepared fields can result in farm surpluses of fish which can provide a valuable source of income.

Other farming enterprises

Diversification of farming enterprises is restricted because farmers live away from their fields in villages situated on higher ground. Some farmers walk up to 5 km to tend their fields. In addition, their farming parcels are not contiguous as the land was recently redistributed by quality and family size. Under these conditions, it is difficult to develop small fields without dramatically affecting the land of neighbors. Fencing is also nonexistent and double cropping with cash crops or green manures is difficult because of interference of grazing animals. However, over recent years there have been isolated incidences of farmers constructing “ditch and dike farming systems,” fish ponds, and watering points for crop irrigation. This intensification needs to increase as the land is placed under further population pressure.

The area around the house is intensively farmed with various fruit trees, vegetables, and herbs. Farmers often graze cattle, grow pigs, and raise chickens. Their protein intake is also improved with the capture of wild food including frogs, crabs, fish, and insects. Some estimates show that 40% of farmers’ protein intake come from wild food (Bolton 1996). Apart from the sale of farm animals, farmers supplement their income by gathering and selling palm sugar, making mats and baskets, and seeking off-farm employment.

Cited references

Bolton M. 1996. Report on exploratory survey of wild food usage by rural households in Svey Rieng Province. Phnom Penh: Cambodia-IRRI-Australia Project. 3 p. (unpubl.)

Bruce RC. 1992. Hectarage of different rice ecosystems in Cambodia. Report. 6 p.

[CIAP] Cambodia-IRRI-Australia Project. 1993. Annual research report. Phnom Penh: CIAP 206 p.

Lando RP, Solieng Mak. 1994a. Rainfed lowland rice in Cambodia: a baseline survey. IRRI Res. Pap. Ser. 152. 20 p.

Lando RP, Solieng Mak. 1994b. Deepwater rice in Cambodia: a baseline survey. IRRI Res. Pap. Ser. 153. 29 p.

Lando RP, Solieng Mak. 1994c. Cambodian farmers’ decision making in the choice of traditional rainfed lowland rice varieties. IRRI Res. Pap. Ser. 154. 17 p.

Rickman JF, Pyseth M, Sothy O, Theavy KC, Sokha N. 1995. Farm mechanization and crop production in Cambodia. Phnom Penh: Cambodia-IRRI-Australia Project. 20 p.

Rice ecosystems and varieties

E. L. JAVIER

Cambodia's rainfall distribution, flooding pattern, topography, and soil types bring about very diverse rice-growing environments. These rice ecosystems can be grouped into broad categories, each category can further be divided into subcategories, and so on. As in many tropical countries where rice is grown, the first level of classification is based on season. Wet season rice is dependent on rainfall between the months of May and November. The major ecosystems in the wet season are rainfed lowland (including lands with supplementary irrigation), deepwater, and upland rice. Deepwater rice ecosystems are controlled greatly by the occurrence and strength of floods coming from the Mekong River. Rainfed lowland ricelands can be subdivided into areas which require early- (high fields), medium- (middle fields), and late-duration (low fields) varieties. Dry season rice is fully or partially irrigated.

Being close to the center of origin of rice, Cambodia has a wealth of land races that fit into different ecosystems. For hundreds of years, natural selection pressures such as drought, submergence, flooding, nutrient stresses, and biotic stresses have contributed significantly to the evolution of various rice varietal types for different environments. Variations in cultural management practices (e.g., harvesting by cutting the panicles vs harvesting by hand stripping individual grains, direct seeding vs transplanting, mixed cropping vs pure stand) and differential preferences of farmers for grain characteristics also contributed to the genetic diversity.

This chapter gives a general description of each ecosystem in terms of production area and productivity; climatic and environmental factors responsible for ecosystem diversity (subecosystems); and production practices, production constraints, varietal types predominantly grown and their characteristics. The breeding strategies envisioned by the Cambodia-IRRI-Australia Project are also discussed. The statistics given on rice production area should be viewed as relative rather than absolute values.

Overview of rice ecosystem area

The present rice ecosystem production area in Cambodia can be examined under three periods—before, during, and after the 1970s. During the 1966-67 crop year, for example, there were about 2.5 million ha of ricefields, about 93 and 7% of which were cultivated in the wet and dry season, respectively (Table 5.1). Rainfed lowland late-duration varieties occupied the largest area with more than 1.5 million ha, followed by deepwater rice varieties with nearly 400,000 ha.

The civil war from 1970 to 1975 and certain Khmer Rouge policies promulgated from 1975 to 1978 brought about a drastic reduction in area grown to rice. Production statistics in the 1980s reflected this reduction. In 1980-81, total rice area was more than 1 million ha less than that in the late 1960s. Considering each ecosystem, late-duration rainfed lowland area was reduced by 790,000 ha; deepwater rice area by 300,000 ha; and medium-duration rainfed low-

Table 5.1 Different rice ecosystems in Cambodia, by area. 1966-95.

Ecosystem	1966-67		1980-81		1994-95	
	Area ('000 ha)	%	Area ('000 ha)	%	Area ('000 ha)	%
Wet season	2,350.0	93.8	1,346.0	93.4	1,868.9	91.7
Rainfed lowland	1,911.1	77.9	1,249.0	86.7	1,746.7	85.7
Early rice	72.3	2.9	224.5	15.6	354.3	17.4
Medium rice	309.8	12.4	245.0	17.0	721.4	35.4
Late rice	1,569.0	62.6	779.5	54.1	671.0	32.9
Deepwater	399.7	15.9	97.0	6.7	84.3	4.1
Upland	-	-	-	-	37.9	1.9
Dry season	181.4	7.2	95.0	6.6	169.2	8.3
Total	2,508.2		1,441.0		2,038.1	

Source of 1966-67 and 1980-81 data: Bulletin of Agricultural Statistics and Studies. 1993 (No. 2) Prepared by the Department of Planning and Statistics, Ministry of Agriculture, Forestry and Fishery (MAFF), Phnom Penh, Kingdom of Cambodia and FAO, Rome, Italy. Source of 1994-95 data: Survey of the Department of Agronomy, MAFF, Phnom Penh, Kingdom of Cambodia.

land area and dry season area by less than 100,000 ha each. However, early-duration rainfed lowland rice area increased by about 150,000 ha. This increase was the result of growing early-duration varieties on a large fraction of an area which traditionally was planted to medium-duration varieties.

There was an upward trend in total rice production area starting in 1980. In 1994-95, total area grown to rice was 2.04 million ha. However, it was still below the 1966-67 level, by as much as 500,000 ha. Deepwater rice area was least affected by this upward trend. The major reason behind the minimal increase in deepwater rice area from 1980 to the present could be traced back to the events that took place in the 1970s. Farmers stopped cultivating ricefields far from their homes (which were often deepwater rice areas) during the civil war (Seng et al 1987). From 1976 to 1978, the Khmer Rouge implemented a development plan that further reduced deepwater rice cultivation. A 3-t ha^{-1} rice yield was set as a goal by the government (Pol Pot 1977 as cited by Lando and Mak 1994c). To achieve this, attempts were made to use some deepwater areas for lowland rice production—water control structures were constructed for the dwarf, early-duration varieties (Seng et al 1987). In other places, farmers were discouraged from growing deepwater rice, or they were forced to plant poorly adapted varieties (Lando and Mak 1994c). In areas where the irrigation intervention failed, a change in flooding pattern was observed, rendering the local varieties less adaptable to the environment. A significant consequence was the permanent loss of many deepwater rice varieties with location-specific adaptation. During that period, there were no facilities for long-term storage of varieties. The civil war and the Khmer Rouge policies had effectively curtailed the only way by which varieties were maintained at the time—by yearly planting of deepwater rice. The absence of suitable varieties in many niches in the deepwater rice ecosystem continues to be a major stumbling block in the expansion of this ecosystem.

By 1995, the area devoted to rainfed lowland rice was only about 160,000 ha less than the 1.91 million ha cultivated in the late 1960s. However, the area occupied by the early-, medium-, and late-duration rices had changed dramatically over time. The production area of early-duration rice increased from 72,000 in 1966-67 to 350,000 in 1994-95. A substantial area previously grown to medium-duration varieties was used for early-duration rice cultivation. In spite of this, medium-duration rice doubled its production area to 721,000 ha, representing 35% of the total rice area in 1995. The medium-duration rice was cultivated in areas traditionally grown to late-duration rice. As a consequence, the production area of late-duration rice in 1995 remained very low (671,000 ha) compared with that in the late 1960s (1.57 million ha). The production area of late-duration rice may further decline if earlier maturing varieties adapted to various niches are found. Farmers are fully aware that the shorter the time a crop remains in the field, the lesser the crop's exposure to risks associated with rainfed lowland rice culture.

The areas cultivated with dry season rice in 1994-95 and 1966-67 were nearly similar in size. It should be noted that only a very small area of the wet season ricefield is planted to a second rice crop in the dry season.

Upland rice areas are very small compared with other ecosystems—from 25,000 to 40,000 ha. The political turmoil in the 1970s had also affected its cultivation. Upland rice areas, particularly those that fall under the slash-and-burn cultivation method, will always be part of Cambodia's agricultural scene inasmuch as the identity and culture of its many ethnic groups are tied up with upland rice growing.

Rainfed lowland rice

The rainfed lowlands of Cambodia are bunded fields that are almost completely dependent on local rainfall and runoff for water supply. Since the quantity and duration of rainfall are variable, floodwater depth and duration likewise vary. Floodwater depth can range from 0 to more than 25 cm. Floodwater depths of 50 cm or more may be experienced for short periods. The rainfed lowlands have variable duration of aerobic conditions as a result of variable rainfall quantity and duration.

Distribution of production area

Rainfed lowland rices are cultivated in all provinces of Cambodia (Plate10). The largest concentration is around the Tonle Sap Lake, the Tonle-Bassac River, and the Mekong River. Over the years, Takeo Province has the largest rainfed lowland area devoted to early-duration varieties. In 1994-95, nearly 80,000 ha were planted to early-duration rice (Table 5.2). It was followed by Prey Veng, Siem Reap, Kampong Cham, Svay Rieng, Kampong Speu, Kampong Thom, and Kampong Chnnang. These eight provinces represented 74% of rainfed lowland areas that grow early-duration varieties. Kampot, Prey Veng, Svay Rieng, Takeo, Siem Reap, and Kampong Cham had the largest areas grown to medium-duration varieties, ranging from 55,000 to 100,000 ha. Late-duration varieties are concentrated in Battambang, Prey Veng, Banteay Meanchey, Kampong Cham, Siem Reap, and Svay Rieng. In the first two provinces, late-duration rice areas have often exceeded 100,000 ha in the past 15 yr.

Table 5.2 Area planted to rice ('000 ha) in each province, by ecosystem, 1994-95.

Location	Wet season					Dry season
	Early	Medium	Late	Deepwater	Upland	
Phnom Penh	0.18	6.35	2.05	-	-	1.24
Kandal	8.22	17.42	16.05	3.68	1.74	38.69
Kampong Cham	28.49	55.08	74.94	0.86	8.13	20.39
Svay Rieng	27.05	74.94	51.94	0.14	0.15	2.70
Prey Veng	48.31	87.30	92.78	0.94	-	34.39
Takeo	78.46	74.03	25.37	7.00		42.49
Kampong Thom	21.21	36.82	35.52	30.8	1.80	2.83
Siem Reap	36.32	60.92	63.91	7.45	7.54	9.04
Battambang	9.35	27.34	125.35	11.29	-	2.18
Banteay Meanchey	14.82	36.72	75.03	14.58	-	
Pursat	16.00	26.00	33.28	4.60	0.12	0.75
Kampong Chhnang	21.25	34.33	21.28	1.79	0.33	7.16
Kampong Som	0.46	6.08	2.26	-	-	
Kaep	0.40	1.50	0.69	-	-	
Kampot	10.24	101.26	16.51	0.69	0.95	0.95
Koh Kong	0.56	2.19	0.52	-	1.93	
Kampong Speu	23.39	44.24	16.35	-	0.68	0.94
Preah Vihear	0.70	8.70	6.40		1.20	-
Stung Treng	5.75	4.21	1.91	0.49	1.59	-
Ratanakiri	0.41	1.46	2.40	-	8.73	0.04
Mondulkiri	0.92	0.75	1.55	-	2.28	-
Kratie	1.81	13.74	4.91	-	0.74	5.42
Total	354.30	721.38	671.00	84.31	37.91	169.21

Source: Survey of the Department of Agronomy, Ministry of Agriculture, Forestry and Fishery, Phnom Penh, Kingdom of Cambodia. 1994-95.

Diversity in rainfed lowland ecosystems

Farmers are fully aware of the diversity in rainfed lowland rice areas. Their experience with this diversity gave rise to the current broad classification of rainfed lowland areas based on three varietal maturity groups—early-, medium-, and late-duration rices. This classification is adopted by the government in preparing statistics on rice cultivation. The general characteristics of the rainfed lowland rice ecosystems are described by Lando and Mak (1994a) and Fujisaka (1988) based on their studies in Kandal, Takeo, and Kampong Speu. The highlights of their studies along with observations of the CIAP breeding team and cooperators from various parts of the country are discussed in the following sections.

There are three interrelated factors in the broad classification of rainfed lowland ricelands: topography, water depth in the field, and varietal type. The varietal classes currently used to categorize rainfed lowland areas have equivalents in terms of field level or water regime classifications. Field levels are described as high (*srai leu*), middle (*srai kandal*), and low (*srai Kraom*). They are distributed in different ways. For example, in some areas, high and middle fields are contiguous; in other areas, a high field is immediately followed by a low field.

Fujisaka (1988) reported water levels of 0-15 cm, 10-30 cm, and 30-80 cm for the high, middle, and low fields, respectively. Lando and Mak (1994a) said that water level seldom surpassed 20 cm in the high fields and was often 20-40 cm in the middle fields. The low fields would often have more than 30 cm of standing water. A water level of 50 cm or more is not uncommon. These observations emphasize the presence of a water gradient, with the high fields having the least standing water and the low fields, the most.

There are appropriate varietal types for the field level or water regime classes. Varieties are broadly grouped according to dates of flowering or harvesting. Early-duration varieties (*srau sral*) are suited to the high fields, medium-duration (*srau kandal*) varieties grow well in the middle fields, and late-duration (*srau thungun*) types are best for the low fields. Farmers classify photo-period-insensitive varieties that mature in less than 150 d and photoperiod-sensitive varieties that flower as late as early November as early-duration rices. Medium-duration varieties flower from mid- to late November and late-duration ones, from early to mid-December. Medium- to late-duration varieties are strongly photoperiod-sensitive.

All fields are exposed to periods of drought and/or flood. The high fields are generally more drought-prone while the low fields are more flood-prone than the others. The middle fields are more drought-prone than the low fields and more flood-prone than the high fields. However, there are sites in each field level that have more favorable water control. Some areas are partially irrigated, although the proportion is quite small. Some areas within the low fields are subjected, like the deepwater rice area, to prolonged periods of floods in certain years.

There is also variation in soil type at each field level, with the high fields having the least variation. The high fields are often sandy. The other field levels have sandy, silt loam, silty clay, or clay soils. In general, soil fertility increases from the high to the low fields.

Diversity among and within the rainfed lowland ecosystems is also enhanced by the variation in cultural practices employed.

Overview of production practices

Lando and Mak (1994a) and Fujisaka (1988) conducted a survey of production practices being followed in the rainfed lowland rice areas in Kandal, Takeo, and Kampong Speu. Rickman et al (1995) recently did the same thing in Battambang, Kandal, Kampong Cham, Svay Rieng, and Takeo. Their observations along with those of CIAP staff and cooperators serve as the basis of this section.

The production practices for rainfed lowland rices are diverse. This diversity is not limited to any particular maturity group, except in a few cases where specific practices are associated with certain maturity groups.

Nursery bed establishment. The most predominant method of crop establishment is transplanting. The first major activity is the preparation of the seedbed. Nursery beds are established in areas where there is good water control. They can be irrigated when there is drought or drained easily when there is excess standing water. Plot size per hectare of ricefield ranges from 0.1 to 0.2 ha.

The nursery area is often plowed and harrowed twice, the interval between the first and the second being 1-2 wk. It is divided into smaller plots by making parallel, deep furrows. A diagonal, deep furrow passing through the parallel furrows is then made. The diagonal furrow is the channel for irrigation water for the nursery area while the parallel furrows are the channels for individual beds. Excess water is drained through these furrows.

Seeding rate varies from 50 to 120 kg ha^{-1}, depending on nursery location and germination rate of the seed. In general, more seeds are used in seedbeds located in the high fields where drought and soil fertility may be a problem. The early-duration varieties are seeded in the high fields.

Seed is pregerminated by soaking in water for 12-24 h and then incubated for 24-36 h. Seed is uniformly broadcast on saturated soil of the seedbed.

The schedule of seedbed establishment depends on the onset and amount of rainfall. Nursery bed preparation may start as early as the middle of May. If early rains are adequate, late-duration varieties are seeded first (mid-May to early June), followed by medium-duration varieties and then by early-duration varieties.

Crop establishment for transplanted rice. The field is plowed twice and harrowed once or twice. The first plowing aims to destroy the weeds. The second plowing is to further destroy the weeds emerging after the first tillage operation and to prepare the field for transplanting. The interval between the first and second plowing depends on available rainfall and maturity of the variety to be grown.

Transplanting starts with the uprooting of seedlings in the nursery. Transplants are bundled and transported to the crop field. Random transplanting is done with 2-3 seedlings $hill^{-1}$ for vigorous seedlings and 4-5 or more seedlings $hill^{-1}$ for less vigorous ones. There are more hills m^{-2} when the soil is less fertile or when seedlings are less vigorous.

The time of sowing and transplanting (and thus the age of seedlings) is influenced not only by rainfall but also by the photoperiod sensitivity of the maturity classes. Highly photoperiod-sensitive varieties can be sown between May and July and transplanted between June and September; they flower only at a particular time. This flexibility is essential in areas where nursery bed and crop establishment are dependent on erratic early rains. The age of transplants for photoperiod-insensitive, early-duration varieties ranges from 20 to 30 d. The age of transplants for the photoperiod-sensitive, early-duration varieties and for other maturity groups ranges from 30 to 90 d; the more frequently used are the 45-60-d-old plants.

Crop establishment for broadcast rice. Materials for broadcasting may be seedlings, pregerminated seed, or dry seed. The land preparation practices employed before broadcasting seedlings or pregerminated seed are similar to those employed for transplanted rice. Practices associated with broadcasting dry seed are similar to those discussed in the deepwater rice section of this chapter. Broadcasting dry seed—especially of late-duration varieties—is common in the northern provinces where a labor shortage exists.

Crop protection. Hand weeding is commonly done 1-4 times, depending on weed intensity. The thoroughness of land preparation as well as the frequency and duration of time when there is no standing water in the field determine weed intensity. Herbicides are seldom used.

Rats are usually controlled by digging their burrows and killing them with the use of stick. Other control methods include chemicals, traps, and mechanical barriers like plastic sheets or woven palm leaves. Crabs are a major source of food in the farm. They are commonly controlled by hand-picking during the seedling stage. They are rarely controlled by chemical and botanical pesticides. Chemical control of insect pests is not commonly done except in some fields near the Vietnam border where early-duration modern varieties are grown. Birds are caught through the use of nets and killed using certain pesticides; some are driven away by bird watchers and scarecrows (Plate 11).

Fertilizer use. Farmyard manure composted solely or with rice straw/dried leaves is the most common fertilizer used in nurseries and fields. Chemical fertilizers may also be used in the fields. If fertilization is employed, the high fields (early-duration varieties) commonly receive more fertilizer than the lower fields.

Harvesting and postharvest operations. Harvesting using hand tools is the practice. The harvest is bundled and sun-dried for 2-3 d. Bundles are transported to the farmer's house and threshed. Winnowing is done by hand, using flat baskets with bamboo rims. Seed is sun-dried on mats for 3-4 d. Seed may be stored in hemp bags, synthetic fertilizer bags, tightly woven baskets, and wattle-and-daub huts built on stilts.

Practices for specific varietal groups. Seedlings of traditional medium- and late- duration varieties are generally tall (Plate 12). Their canopy is heavy and drooping. The top leaves are often cut by hand to produce shorter, stiffer seedlings that are more resistant to lodging and have a lower transpiration rate. The length of the top leaves to be removed varies, depending on the floodwater level in the ricefield at the time of transplanting.

Late-duration varieties are planted in the low fields which are generally more fertile than the high fields. They may grow very fast and develop profuse vegetation, with drooping leaves. During the stem elongation phase, some farmers remove the top canopy to prevent lodging. The top of the canopy is cut with a sickle and the leaves used as animal feed. Sometimes, cows are allowed to graze the canopy down.

At ripening, tall varieties with heavy panicles lodge easily (Plate 13). When the wind direction changes, crop lodging occurs in various directions. Harvesting is more laborious when lodging is nondirectional. Thus, some farmers make the crop lodge in one direction using a bamboo pole.

Production constraints

Rice productivity in Cambodia is the lowest in Asia. This is mainly due to the low productivity of all rainfall-dependent rice ecosystems which represent at least 91% of the total rice area. In 1990, the average yields of the early-, medium-, and late-duration rainfed lowland rices were 1.59, 1.42, and 1.38 t ha^{-1}, respectively, while the national average was 1.45 t ha^{-1} (CIRP 1991). In 1991, the late-duration rice varieties had the highest mean yield (1.31 t ha^{-1}), followed by medium-duration (1.30 t ha^{-1}) and early-duration (1.27 t ha^{-1}) varieties (CIRP 1992). The national average yield in the same year was 1.39 t ha^{-1}. The inconsistency in maturity group performance and their generaly lower yields suggest the existence of serious constraints to productivity. Production constraints were identified by Lando and Mak (1994a) for rainfed lowlands in Kandal, Kampong Speu, and Takeo. These same constraints can also be found in other parts of the country.

Erratic rainfall. The uncertainty of occurrence, duration, and amount of rainfall affects substantially the productivity of the rainfed lowland rice ecosystem. Inadequate rains in May and June delay seedbed establishment, lead to poor land preparation, favor the buildup of thrips, armyworms, and mole crickets in the nursery, and produce less vigorous seedlings. Inadequate rains in July and August delay transplanting, lead to poor transplant recovery, and poor vegetative growth. The dry soils also encourage weed growth. In general, the unfavorable effects of insufficient rains from May to August are mostly felt in the high fields where early-duration varieties are grown; the least effect is experienced in the low fields planted to late-duration varieties.

Excessive rains from September to October, coupled with the high floodwater level in the Tonle-Bassac and Mekong rivers, cause flooding in the rainfed lowlands. This effect is greatest in the low fields and least in the high fields. The strong current of flash floods laden with silt can damage leaves and submerge the crop for a number of days. Flash floods can reduce plant density. Reduced rains in October and early cessation of rains in November can adversely affect the yield of the crop during its reproductive stage. The most affected are the late-duration varieties, followed by the medium-duration varieties.

Of the 1.9 million ha planted in the 1995 wet season, about 216,000 ha and 15,000 ha were affected by flood and drought, respectively (DA 1995). The area completely damaged by flood was about 138,000 ha, while that completely damaged by drought was about 9,000 ha. The area affected by abiotic stresses in 1995 could be considered small compared with that in other years because 1995 had one of the most favorable environmental conditions in recent years.

Pests. The three maturity classes share common crop protection problems. The incidence of weeds is usually a problem when standing water is not maintained in the fields. Crabs can damage seedlings and birds eat broadcast seed plus ripening grain. Rats attack the crop at any stage of growth but are particularly attracted to the crop during booting.

A number of insect pests cause damage in rainfed lowland rice—gall midge, stem borer, brown planthopper, green leafhopper, thrips, grasshopper, leaffolder, rice bug, case worm, and army worm. The reported diseases include sheath blight, bacterial blight, and sheath rot. In general, these diverse insect pests and diseases are not considered major problems. The high population of predators and parasites, the infrequent use of pesticides, and varietal diversity in farmers' fields could be responsible for the low insect pest and disease problems.

Poor soils. Cambodian soils are generally infertile as a result of continuous cultivation without adequate replenishment of lost nutrients. Most soils are deficient in nitrogen and phosphorus; some may be potassium-deficient. Iron toxicity is observed in some soils. In general, soil fertility increases from the high to the low fields. The high fields have the highest sand content, and therefore the poorest water- and nutrient-holding capacity. The low fields are the most fertile. However, some soils are still poor in terms of N and P content.

Varieties and related issues, Many traditional varieties being cultivated give low yields. Farmers continuously rely on these varieties because of their good grain qualities or adaptability to specific abiotic stresses (Lando and Mak 1994a). The general seed purity is quite low and farmers cultivate more than one variety. They produce their own seed and varietal mixing can take place any time during the period between harvest through transplanting. Poor on-farm seed storage results in lower seed viability and farmers often have to resort to applying high seeding rates.

Socioeconomic constraints. The average farm size can vary from <1 to >3 ha, depending on locality. The farm is composed of small plots distributed in at least two ecosystems. For example, a family may have a plot in the high field, one in the middle field, and another in the low field, or a family may have a plot in the rainfed lowland ecosystem, a plot in the deepwater area, and a plot in an area cultivated in the dry season. Therefore, different ecosystems share the same socioeconomic constraints.

Inadequate labor, farm power, and cash are socioeconomic constraints that beset Cambodian rice farmers in general. The competition for labor and farm power is stronger when the timing of farm activities (like land preparation and transplanting) becomes too close for all maturity classes as a result of inadequate early rains. Most farmers are poor. Consequently, their limited access to credit facilities hinder the hiring of labor and purchase of farm machinery and fertilizer.

Traditional varieties

A characterization study of traditional varieties was conducted by CIAP (Sahai et al 1992a, 1992b; CIAP 1993, 1994) and the results from this study form the basis of this section. A few traditional deepwater and upland rices were included.

Of the 1.75 million ha of rainfed lowland rice cultivated in 1995, about 94% were grown to traditional varieties (DA 1995a). Different varieties have evolved for different rice ecosystems. A given traditional variety is genetically heterogeneous. It is composed of different purelines produced through the combined effects of occasional cross pollination, genetic recombination, mutation, and selection over hundreds of years. Natural selection pressures include field water levels, drought, flash flood, submergence, and pests at different stages of growth. Continuous crop cultivation without sufficient replenishment of nutrients lost adds infertile soils to the abiotic stresses traditional varieties are subjected to. The farmers' contribution to genetic diversity is selection for certain grain characteristics and agronomic practices.

Of the 1,594 varieties analyzed before the end of 1994, less than 2% were photoperiod-insensitive and 98% were photoperiod-sensitive. The photoperiod-insensitive varieties have short growth duration while the sensitive ones have longer maturation periods. The very high proportion of photoperiod-sensitive varieties indicates that photoperiod sensitivity is a survival trait for unfavorable rainfall-dependent rice cultures of Cambodia. It allows such varieties to be planted early or late, depending on rainfall availability, and to still flower at a particular time. Flowering time should fall when drought is less likely to occur. There is variation in the degree of photoperiod sensitivity, with strongly sensitive varieties constituting 93% of the collection.

The mean, range, and coefficient of variation for some agronomically important quantitative characters of 2,109 traditional varieties evaluated by CIAP are shown in Table 5.3. The farmers' classification of the rainfed lowland ecosystem into three maturity classes reflects their awareness of the wide variation in growth duration of traditional varieties. They consider number of days from seeding to harvesting for photoperiod-insensitive varieties and time of harvesting for photoperiod-sensitive ones. The growth duration of a variety is defined in terms of number of days from seeding to 50% flowering. In general, it takes about 30 d from 50% flowering for the crop to mature. The number of days to 50% flowering can be as low as 64 d (set II) and as high as 194 d (set IV).

In the rainfed lowlands, there is a gradient of water levels from the high to the low fields. Crop survival is partly determined by the crop's height relative to the field water level. A portion of the crop canopy should be above the field water. In the collection, seedlings can be as short as 10.4 cm (set I) and as tall as 44.2 cm (set IV). Variability for culm length is also present, ranging from 15 cm (set III) to 225 cm (set I). Traditional tall varieties are common. In the low fields, tall plants have better survival ability than short plants.

The ability to withstand drought and the ability to recover immediately from drought when water becomes available are important survival mechanisms. Few varieties possess the first trait, but many varieties possess the second trait (Chaudhary and Sahai 1993). Drought recovery is the major mechanism for survival under moisture-deficient conditions in Cambodia.

Lodging is a common problem when varieties are tall. This takes place at the vegetative stage when there is luxuriant growth and at the ripening phase when the panicles are heavy. Strong wind, heavy rains, and flash floods can also bend the crop. One indicator of resistance to lodging is culm diameter. Variation for this character is noted, ranging from 2 to 9 mm. In general, varieties with thick culm do not lodge (Chaudhary and Sahai 1993).

Table 5.3 Mean and range (in parentheses) for some quantitative characters involving four sets of traditional varieties.

Character	Mean (range)			
	Set I[a]	Set II[b]	Set III[c]	Set IV[d]
Days to 50% flowering	123.0 (76-149)	96.0 (64-140)	131.0 (101-163)	145.0 (85-194)
Seedling height (cm)	17.9 (10.4-24.8)	27.8 (13.5-39.5)	33.1 (24-48)	23.6 (12.8-44.2)
Culm length (cm)	111.8 (33-225)	90.3 (47-135)	128.0 (15-177)	99.0 (58.3-153.3)
Culm diameter (mm)	6.1 (3-8)	5.8 (4-9)	5.5 (3-8)	4.9 (2-9)
Culm number	12.6 (5-26)	12.8 (4-28)	9.7 (4-14)	12.0 (6-27)
Panicle length (cm)	23.9 (16.5-35.0)	23.9 (32.0-23.9)	23.8 (17-30)	24.5 (13.3-32.3)
Leaf length (cm)	49.0 (18.5-85.0)	39.9 (23.0-58.6)	43.9 (26-68)	41.9 (10.7-70.0)
Leaf width (cm)	0.8 (0.3-1.9)	0.8 (0.5-2.2)	1.0 (0.4-1.4)	8.6 (0.4-1.5)
Grain length (mm)	6.4 (4.7-9.0)	6.4 (5-9)	8.6 (5.5-11.0)	8.9 (6.7-11.3)
Grain width (mm)	2.4 (1.8-3.4)	2.5 (1.8-3.1)	2.6 (0.3-3.5)	2.6 (1.9-3.4)

[a]1,270 collections evaluated in 1990-91 at Prey Phdau Station (Sahai et al 1992). [b] 348 collections evaluated in 1991-92 at Prey Phdau Station (Sahai et al 1992a). [c] 226 collections evaluated in 1993-94 at Prey Phdau Station (CIAP 1993). [d] 265 collections evaluated in 1994 wet season at Kap Srau Station (CIAP 1994).

Culm number and panicle length are two components of yield. The total number of productive and nonproductive tillers is determined after flowering. It ranges from low (4) to high (28). Transplanting and direct seeding cultures may require different tillering characteristics. Panicle length can range from 13.3 cm (set IV) to 35.0 cm (set I). For low-tillering varieties, good yield is possible if they have long panicles with a high percentage of filled grains.

Leaf dimension was measured using the leaf below the flag leaf on the main culm. Leaf length varies from short (10.7 cm) to long (85.0 cm) and leaf width, from narrow (0.3 cm) to broad (2.2 cm). Leaves that are short, erect, and narrow utilize light efficiently and are suited to favorable rainfed lowland ecosystems. In an unfavorable rainfed lowland environment, leaves that are long, broad, and droopy favor shading and thus, are less efficient in light utilization. However, such characters may be effective in weed competition and in covering the ground to prevent moisture loss especially in times of low rainfall.

Grain length is highly variable, ranging from short (4.7 mm) to extra long (11.3 mm). Based on the coefficient of variation, grain width is more variable than grain length. The grain length-width ratio provides information on grain shape—e.g., slender (value >3.0), medium (2.1-3.0), bold (1.1-2.0), and round (< 1.1) (IRTP 1988). Most farmers consider long, slender grains desirable.

There are a few glutinous varieties, which are mostly early-maturing. They are used mainly in the preparation of sweets. Nonglutinous rice is preferred; it is aromatic, often soft when cooked, and has good volume of expansion. However, there are only a few scented varieties.

Traditional varieties with awns are rarely found. The presence of awns is a grain characteristic that could have been selected against over hundreds of years of rice cultivation. Awns can be irritating during grain handling.

Since farmers' fields have varying levels, different maturity classes are grown. For a given maturity class, they may grow more than one variety. Farmers look for varieties with high and stable yield and good grain quality. Stability in yield performance is brought about by resistance to or tolerance for drought, flash flooding, submergence, lodging, nutrient deficiencies/toxicities, and biotic stresses. Drought tolerance is more critical for varieties grown in the high fields, while flash flood and submergence tolerance are more critical for those in the low fields. Slight elongation ability is important to enable crops to survive initial total submergence in low fields which are prone to rising floodwater. Seed dormancy is always a desirable attribute to ensure that grains will not germinate when they become moist as a result of continuous heavy rains or when they are submerged in water after lodging. There should be a wide range of growth duration for photoperiod-insensitive varieties, possibly less than 120 d but not more than 150 d. Similarly, there should be a wide range of flowering period for photoperiod-sensitive varieties. Variation in growth duration/flowering time is necessary to satisfy the various ecological niches in the rainfed lowland rice ecosystem.

Breeding strategies

In the late 1960s, IRRI distributed modern rice varieties to various national agricultural research systems. They were photoperiod-insensitive, high-tillering, and semidwarf plants with stiff straw for lodging resistance and erect leaves for efficient light utilization; they could thus respond favorably to high levels of fertilizers. The cultivation of these modern varieties under a high fertilizer regime in irrigated lowland environments (seed-fertilizer-water technology) increased rice productivity and brought about the Green Revolution in many rice-growing countries. The social and political instability in Cambodia in the 1970s and its close-door policy in the 1980s isolated the country during the Green Revolution era. Cambodian farmers were introduced to its first modern variety, IR36, years after it has been widely accepted in other countries. To place the country on the mainstream of research, CIAP has embarked on breeding programs to develop improved rice varieties appropriate to the various rice ecosystems.

The rainfed lowland varietal improvement program is divided into three subprograms based on early-, medium-, and late-duration classes. However, the three maturity groups in the breeding program are defined differently, in contrast to the farmers' definition (see subsection Diversity in Rainfed Lowland Ecosystems). In the breeding program, the following definitions are used:

1. early-duration—photoperiod-insensitive varieties that mature in less than 120 d
2. medium-duration—photoperiod-insensitive to weakly sensitive varieties that mature in 120-150 d and photoperiod-sensitive varieties that flower from mid-October to mid-November
3. late-duration—photoperiod-sensitive varieties that flower after mid-November

The above classification provides a better focus for breeding purposes. For example, farmers classify all photoperiod-insensitive varieties under the early-duration group while breeders classify photoperiod-insensitive varieties into two—those that mature in less than 120 d (early) and those that mature between 120 and 150 d (medium). Conducting a separate testing/selection program for photoperiod-insensitive, early - and medium-duration varietal groups is better than a single testing/selection program since some varietal characteristics required in each maturity group differ.

Germplasm conservation. The success of any breeding program depends, to a large degree, on crop generic variability. The major source of variation is always the traditional germplasm of the country where the improved variety is to be commercially grown. Traditional varieties can be used directly in the testing program or indirectly as parents in the hybridization program. Germplasm conservation therefore is an integral part of any varietal improvement program.

Germplasm collection in Cambodia can be divided into three phases. The first phase covered the collection completed by the Kingdom of Cambodia and IRRI before and during the early 1970s. Around 800 traditional varieties were collected and stored at IRRI. The collection included traditional varieties lost during the civil unrest in Cambodia. The second phase, covering the period from 1989 to 1993, was a collaborative undertaking of the Department of Agronomy, provincial agricultural offices, nongovernment organizations (NGOs), and CIAP. Around 2,200 varieties were collected from 17 provinces; these were then characterized and stored at IRRI headquarters and at CIAP. The third phase started in 1995 and will end in 1997. It is being funded by the Swiss Development Cooperation (SDC) under IRRI's biodiversity project. Collection of traditional varieties will be done in provinces not covered in the past. Further, wild relatives of rice will be collected in as many provinces as possible.

Direct use of traditional and foreign varieties. It takes a minimum of 5 yr from the time different varieties are hybridized to the time pureline selections are fully evaluated in multilocation trials to know if materials are photoperiod-insensitive (i.e., can be grown in both wet and dry seasons). If photoperiod-sensitive materials are desired, the minimum time required to release the product of this hybridization and selection process is 10 yr, since these varieties flower only at a particular time of the year. For Cambodia's breeding program (which is relatively young), the fastest and cheapest way to produce an improved variety is to select among and within traditional or foreign varieties. Selection within a traditional variety (land race) is possible inasmuch as it is composed of different purelines. The best pureline is identified, tested, and released back to the farmers. The number of years to generate an improved variety using this scheme is only half the time needed to produce a variety through hybridization and selection in segregating populations. Toward the end of 1996, nine selections from traditional varieties had been released in Cambodia using the above strategy.

The CIAP obtains foreign varieties directly from other rice-growing countries and more often, indirectly through the International Network for Genetic Evaluation of Rice (INGER). INGER has different ecosystem nurseries, each nursery being composed of outstanding varieties or breeding lines from different countries. The CIAP requests from IRRI nurseries entries that are appropriate for the rice-growing environments in Cambodia. All seven modern varieties sponsored by CIAP for commercial use in rainfed lowland ecosystems were developed in other countries.

Hybridization and selection. Hybridization and selection in segregating populations are necessary when combination of desirable attributes could not be found in a single traditional or introduced variety. Many national and international research institutes are actively involved in the improvement of early-duration varieties for rainfed lowland environments and they can very well provide Cambodia a regular supply of such materials. CIAP therefore focuses its efforts on the development of medium- and late-duration photoperiod-sensitive materials.

Very few national programs are involved in developing photoperiod-sensitive varieties. Research is limited because countries are located at different latitudes—times of flowering of varieties coming from various countries would differ. For example, photoperiod-sensitive varieties from India and Bangladesh (high latitude) will flower earlier (around September) than those in Cambodia (low latitude); those from Cambodia will flower later than those in India and Bangladesh. Since the earliest flowering time targeted for photoperiod-sensitive varieties in Cambodia is October, very few materials from the strong breeding programs of India and Bangladesh are useful. In view of this, CIAP has embarked on the development of photoperiod-sensitive varieties to meet the country's future needs. IRRI supports CIAP by providing segregating populations derived from crosses between Cambodian varieties and improved varieties.

Selection environments. The environment under which selection is conducted indicates the environment in which a selected variety will perform well. Cognizant of the limited resources of the farmers, the low fertility of most Cambodian soils, and the risks associated with rainfed lowland rice culture, the present yield trials are conducted using a low level of fertilizer (20 kg N, 4.4 kg P 8.3 kg K ha^{-1}). In some research sites, supplementary irrigation is being done; in others, rainfall is a critical factor and the crop is often exposed to drought, flash flood, and submergence.

On-farm variety adaptation trial. In each maturity group, released varieties and/or outstanding selections in multilocation on-station trials are channeled into the on-farm adaptation trials (OFATs) (Makara et al 1995). This nonreplicated trial is conducted by farmers in their farms using their own resources and management practices and their best variety as check.. Each variety is grown in a 100-m^2 plot. Farmers keep the harvest. In OFATs, farmers are given the opportunity to select the variety(ies) suited to their individual management methods and needs. OFATs also serve as a demonstration area to attract neighboring farmers. It is a major venue by which new varieties are disseminated. As a seed source, OFATs have an important role to play since Cambodia has no seed industry to speak of. Through OFATs, researchers become aware of the farmers' varietal requirements.

Varietal releases

A total of 16 varieties identified in the CIAP testing program have been approved by the Varietal Recommendations Committee (VRC) of Cambodia for rainfed lowland ecosystems since 1990 (Table 5.4). There are four early-duration varieties which are also suited to dry season rice cultivation.

Modern medium-duration varieties. Santepheap (*santepheap* means peace in Khmer) 1, Santepheap 2, and Santepheap 3 are modern medium-duration varieties. The first two are photoperiod-insensitive and were developed by IRRI. Santepheap 3 is a weakly sensitive variety developed at the Orissa University of Agriculture and Technology in India. They mature in less than 140 d and have intermediate plant stature (Table 5.5). The average yields in advanced yield trials fertilized with 60 kg N, 13.2 kg P, and 24.9 kg K ha^{-1} were 3.9 t ha^{-1} for Santepheap 1 and 4.0 t ha^{-1} for Santepheap 2 and Santepheap 3. They have at least a 14% yield advantage over check variety IR42.

In 280 on-farm variety trials conducted from 1992 to 1995, the three varieties had higher mean yields than the farmers' best varieties. Santepheap 3 had a 16% yield advantage; Santepheap 2, 8.3 %; and Santepheap 1, 4.2 %. In OFATs, farmers generally apply low levels of fertilizer. Farmers were asked to identify their first and second preferences among varieties tested. Some farmers identified two first preferences and two second preferences. Santepheap 3 was the most preferred variety, being ranked first by 130 farmers. Santepheap 1 and Santepheap 2 were ranked first by 64 and 68 farmers, respectively. Local checks were given first preference by 16 farmers. All recommended varieties had a higher second preference score than the check. The differential preference suggests that different varieties could find their own niche in farmers' fields.

Table 5.4 Recommended varieties sponsored by CIAP for the rainfed lowland rice ecosystem of Cambodia.

Variety	Designation	Origin	Year released
Early duration[a]			
IR66	IR32307-107-3-2-2	IRRI, Philippines	1990
IR72	IR35366-40-3-3-2-2	IRRI, Philippines	1990
Kru	IR13429-150-3-2-1-2	IRRI, Philippines	1990
Kesar	IR48525-100-1-2	IRRI, Philippines	1993
Medium duration			
Santepheap 1	IR43342-10-1-1-3-3	IRRI, Philippines	1992
Santepheap 2	IR45411-40-2-1	IRRI, Philippines	1992
Santepheap 3	OR142-99	OUAT, India	1992
CAR 1	Pram Bei Kuor (PPD679)	Cambodia	1995
CAR 2	Sambak Kraham (PPD597)	Cambodia	1995
CAR 3	Sraem Choab Chan (Germplasm B-293)	Cambodia	1995
Late duration			
CAR 4	Changkom Ropeak (Germplasm B-528)	Cambodia	1995
CAR 5	Kantouy Touk (PPD156)	Cambodia	1995
CAR 6	Sae Nang (Germplasm B-429)	Cambodia	1995
CAR 7	Changkong Kreal (PPD 723)	Cambodia	1996
CAR 8	Phcar Sla (PPD 364)	Cambodia	1996
CAR 9	Srau Kol (PPD 86)	Cambodia	1996

[a]Also recommended for the dry season.

Table 5.5 Agronomic characteristics of recommended modern medium-duration varieties.

Variety	Station trials				Yield in on-farm trials (t ha^{-1})[a]					
	Duration (d)	Height (cm)	Yield (t ha-l)	% YA[b]	1992	1993	1994	1995	Mean	% YA
Santepheap 1	133	106	3.9	14.7	2.7 (87)	2.3 (56)	2.4 (76)	2.5 (58)	2.5 (277)	4.2
Santepheap 2	136	108	4.0	14.3	2.9 (87)	2.4 (57)	2.4 (76)	2.6 (58)	2.6 (278)	8.3
Santepheap 3	138	106	4.0	17.6	3.1 (87)	2.5 (57)	2.5 (77)	2.8 (58)	2.8 (279)	16.7
Check[c]	-	-	3.4/3.5[d]	-	2.5 (87)	2.3 (55)	2.2 (74)	2.5 (58)	2.4 (274)	-

[a] Values in parentheses refer to number of trials conducted. [b] YA is the yield advantage of the recommended variety over the check. [c] Check variety for station trials was IR42 while that for on-farm trials was the farmer's best variety. Check variety differs from site to site. [d] First value to be used when comparing Santepheap 1 and 3 with the check; second value for comparing Santepheap 2 with the check.

Santepheap 3 appears to have a wider adaptation than Santepheap 1 and Santepheap 2. For example, in the 1995 OFATs, eight farmers reported a period of drought. The mean yield of Santepheap 3 was 2.3 t ha^{-1} while that of farmers' varieties was 2.2 t ha^{-1}. Santepheap 1 had 1.9 t ha^{-1}, while Santepheap 2 had 2.0 t ha^{-1}. Another example involved the trials conducted in Pursat Province in 1994. The Pursat Agronomy Office in collaboration with UNDP conducted OFATs in 59 sites while CIAP conducted theirs in 11 sites. In the CIAP trials, the farmers applied their own cultural management practices which often involved low fertilizer levels. In the Pursat-

UNDP Project, farmers were provided with fertilizers equivalent to 60 kg N, 13.2 kg P and 24.9 kg K ha^{-1}. In Krakor District (where CIAP had 11 trials and the Pursat-UNDP Project had 19), only Santepheap 3 had higher mean yield than the local checks. In Kandieng and Phnom Kravang districts, all the recommended varieties had higher mean yields than local checks. However, in Prey Nhy Subdistrict at Sampoa Meas District, none of the recommended varieties yielded higher than the farmers' varieties. The results in Prey Nhy reflect OFAT's usefulness in determining the suitability of new varieties in specific locations.

In 1995, the Cambodia-Canada Development Program used Santepheap 3 in their rice production program in Krakor and Sampoa Meas districts in Pursat, covering an area of about 95 ha and involving 373 farm families. Estimated yield was about 3.0 t ha^{-1}, which was higher than the expected yield from nearby farms planted to traditional varieties. In one of the farmers' field days, sensory evaluation of the modern variety and four commonly grown traditional varieties in the area was conducted with 67 farmer-evaluators. Santepheap 3 had an acceptability rating of 78%, which was higher than that given to traditional varieties (except for one). This somehow changed the general perception that many modern varieties have poor eating quality. Santepheap 3 has medium-sized grains, Santepheap 1 has long slender grains, while Santepheap 2 has extra long, slender grains.

The spread of the new varieties is quite slow because of the absence of a seed industry in Cambodia. However, with more NGOs becoming interested in conducting rice production programs using improved varieties, varietal spread will be faster. The varietal testing program for modern medium-duration varieties currently uses a fertilizer rate that is only one-third of the rate used for Santepheap varieties. The new rate approximates the low level of fertilization in farmers' fields. It is hoped that a new set of varieties suited to other conditions in the high fields will be generated.

Traditional varieties. The Prey Phdau Station at Kampong Speu played a significant role in the utilization of traditional varieties in Cambodia. In the 1980s, its varietal testing program was strongly supported by the Partnership for Development in Kampuchea (PADEK). During that period, Cambodian traditional varieties stored at IRRI (collected before the height of political instability) were sent back during various occasions and evaluated at Prey Phdau. When CIAP implemented its comprehensive varietal improvement program, collection of traditional varieties was again initiated and new collections were initially evaluated at Prey Phdau. From these old and new collections, three medium-duration (Cambodian Rice [CAR] 1, CAR 2, and CAR 3) and six late-duration (CAR 4-CAR 9) varieties were extracted (Table 5.4). CAR 1, CAR 2, CAR 5, CAR 7, CAR 8, and CAR 9 were pureline selections originating from the old collection which could have been lost completely had they not been conserved at the IRRI gene bank. CAR 3, CAR 4, and CAR 6 were from the new collection. In this instance, the value of genetic conservation has once again been demonstrated.

All varieties are strongly photoperiod-sensitive (except CAR 3), a trait required in the unfavorable rainfed lowland ecosystem. When seeded in early June, the medium-duration varieties flower in early November, while the traditional late-duration ones flower in mid-November at Kap Srau Station, Phnom Penh. All have high yield potential at fertilizer rates of 20-30 kg N, 4.4-6.6 kg P, and 8.3-12.4 kg K (Table 5.6). All varieties are more than 120 cm high, with the traditional medium-duration varieties being slightly shorter than the traditional late-duration lines. Acceptability of raw rice was at least 90% for all varieties (except CAR 3 with 73% acceptability). All have medium-sized grains, intermediate amylose content (21.3-23.2 %), and

Table 5.6 Performance of recommended traditional varieties in station and on-farm trials.[a]

Variety	Station trials			On-farm trials				
	Yield (t ha^{-1})	Height (cm)	Yield across sites (t ha^{-1})	Yield as affected by fertilizer (t ha^{-1})			Yield as affected by abiotic stress (t ha^{-1})	
				Added	Absent	Absent	Drought	Flood
Traditional medium-duration								
CAR 1	3.1	127	2.7	2.9	2.6	2.8	2.7	2.7
CAR 2	3.3	126	2.7	2.9	2.6	2.7	2.7	2.7
CAR 3	3.3	122	2.8	2.9	2.7	2.9	2.5	2.4
Local check		-	2.4	2.6	2.3	2.5	2.4	2.3
Traditional late-duration								
CAR 4	4.0	132	2.7	3.1	2.5		-	
CAR 5	3.7	134	2.5	2.9	2.4		-	
CAR 6	3.8	129	2.7	3.0	2.5		-	
Local check			2.3	2.7	2.5		-	
CAR 7	3.5	147					-	
CAR 8	3.5	146					-	
CAR 9	3.4	137					-	

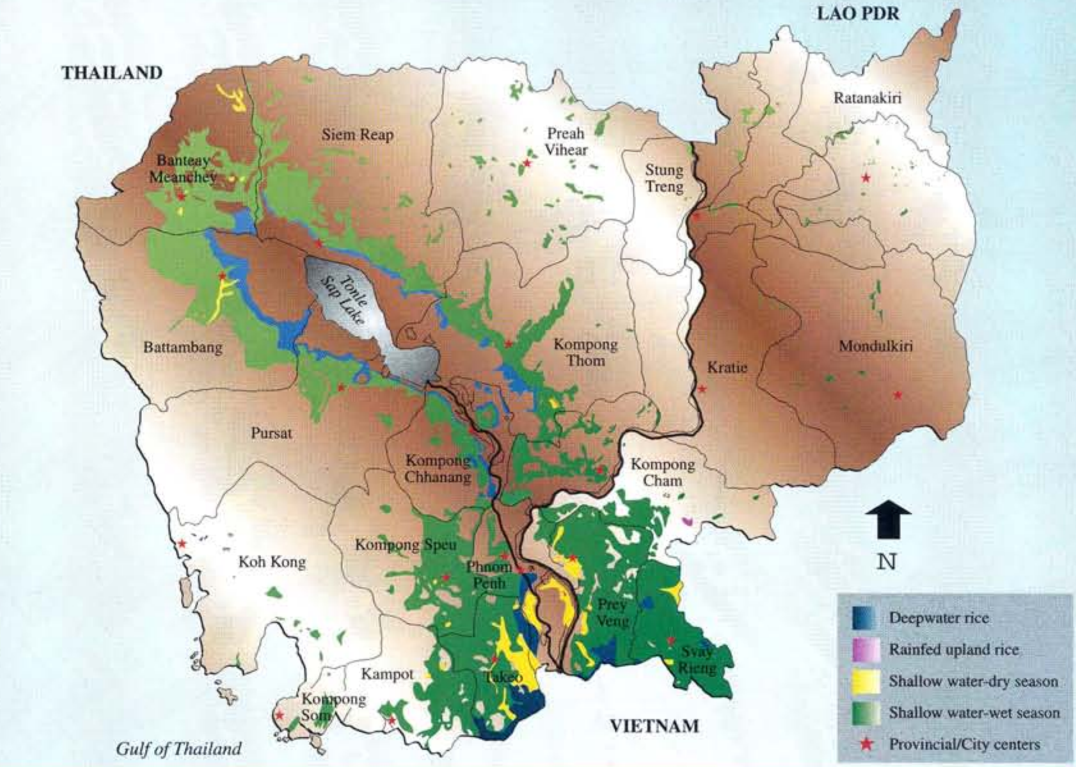
[a] 107 OFATs for medium-duration varieties and 78 OFATs for late-duration varieties.

medium to very soft gel consistency. The last two characteristics imply that the recommended varieties are soft and have a high volume of expansion when cooked. Cooked rice acceptability ranged from 82 to 99%.

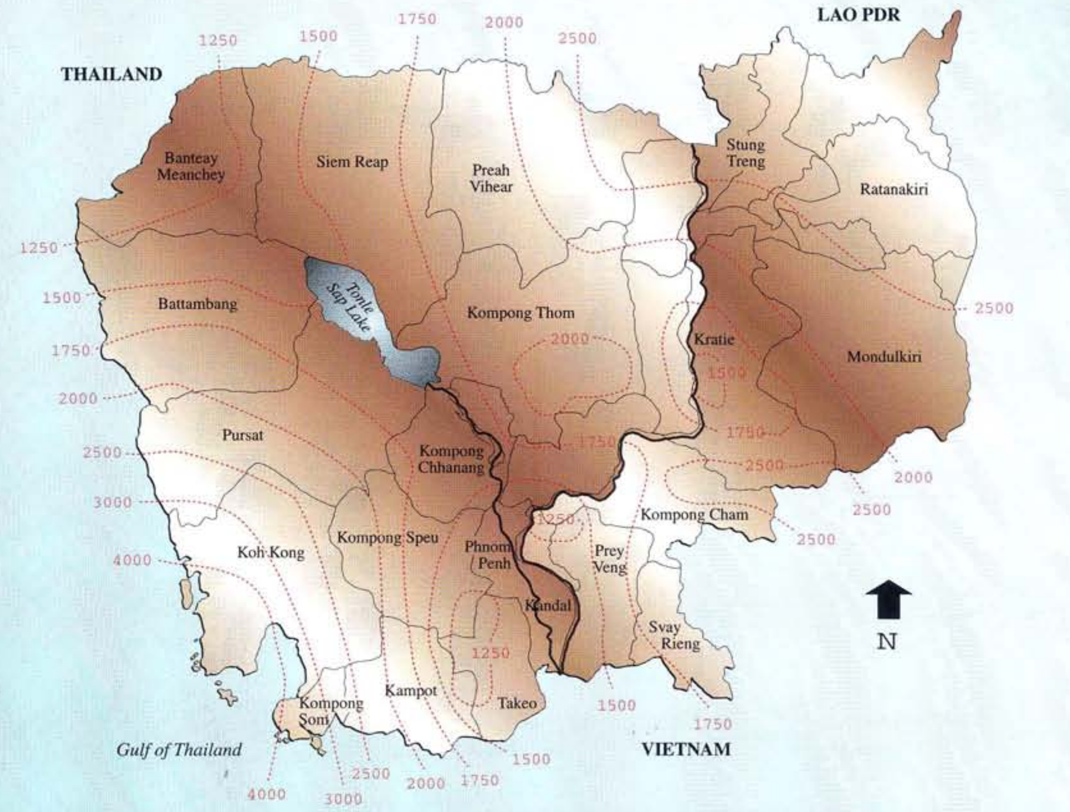
CAR 1, CAR 2, and CAR 3 performed well when tested in farmers' fields in 1995. In 107 OFATs, the mean yield of each of the recommended varieties was higher than that of the local checks (2.6 t ha^{-1}). CAR 3 had the highest yield (2.8 t ha^{-1}). In 48 trials where fertilizer was applied, the recommended varieties had a 12% yield advantage over the local varieties. Where no fertilizer was applied (59 trials), the yield advantage of the recommended varieties was even higher. CAR 3 had the highest mean yield (2.7 t ha^{-1}). When OFAT results were classified according to abiotic stresses encountered, the new varieties were found to be superior to local checks. However, CAR 1 and CAR 2 gave better yield than CAR 3 during periods of flood or drought. Farmers differed in their varietal preferences. Very few farmers preferred their own varieties. More farmers said that their first preference were CAR 1 and CAR 3.

CAR 4, CAR 5, and CAR 6 were evaluated in 78 sites. All had higher yields across sites than the local varieties, the yield advantage being at least 8.7%. With or without fertilizer inputs, the three varieties were superior to the local varieties. It was thus not surprising that most farmers preferred them over their own varieties. CAR 4 had the most number of first preferences (38), followed by CAR 6 (27).

CAR 6, CAR 7, and CAR 9 are currently entered in the 1996 OFAT along with the other recommended traditional varieties. The CIAP plans to release as many high-yielding, photoperiod-sensitive varieties with stable performance as possible. This will give farmers a wider range of selection for their varied field conditions. Greater attention will be given to varieties whose flowering times differ from those of current varieties—earlier than medium-duration varieties released and later than late-duration ones.



MAJOR RICE AREAS IN CAMBODIA



RAINFALL MAP FOR CAMBODIA

Plate 1. Rice was irrigated and cultivated in the rainfed lowland, deepwater, and upland areas during the Angkor period (10^{th}-14^{th} century AD).

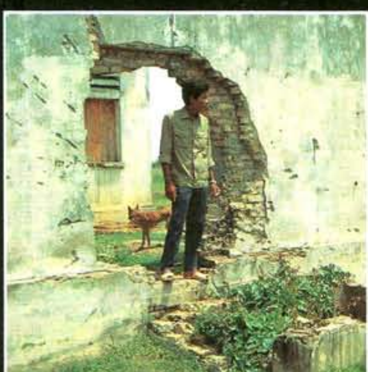


Plate 2. Much of the agricultural research infrastructure was destroyed during the Pol Pot period (1975-78).

Plate 3. The major rice-producing areas of Cambodia are flat and susceptible to flooding.

Plate 4. Drought during the rice-growing period can be a serious problem for rainfed rice production.

Plate 5. Many of the soils in the rice-growing areas are impoverished and must be well managed to maximize yields.

Plate 6. Some farmers apply manure to their land as the sole source of fertilizer.

Plate 7. Progressive farmers are reforming part of their rainfed land to grow other crops in addition to rice.

Plate 8. Seedlings of photoperiod-sensitive rices may be planted over an extended period of time.

Plate 9. Animals form a major part of the total farming system in Cambodia.

Plate 10. Rainfed lowlands form a major part of the rice-growing environment of Cambodia.

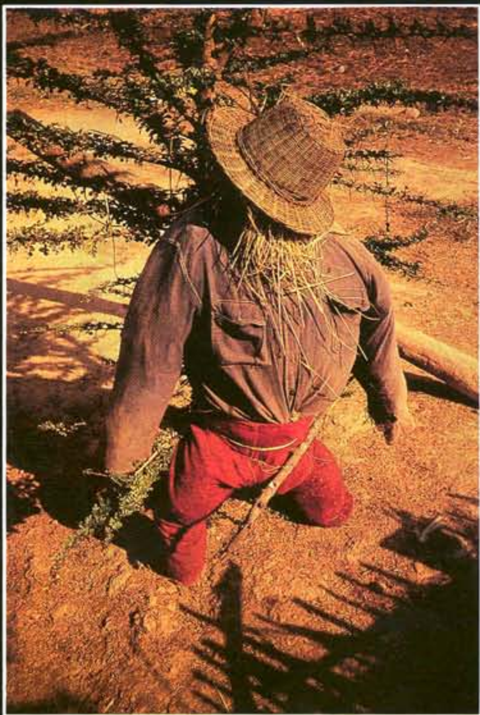


Plate 11. Some novel ways of scare tactics are used by farmers to ward off pests.

Plate 12. Late-season rices are tall varieties and flower late in the year.

Plate 13. Late-season rices often lodge when the water levels recede.

Plate 14. Irrigated rice soils are more fertile beside rivers and mountainous areas.

Plate 15. Deepwater rice areas are found along the rivers and edges of the Grand Lake.

Plate 16. Upland rice is often planted with other crops in the northeastern provinces.

Plate 17. Draining fields assist in the control of some insect problems and may provide access for fish.

Plate 18. The golden apple snail was introduced into Cambodia in 1995 as a food source and eventually spread to the rice-growing areas.

Plate 19. The use of agricultural equipment including two- and four-wheel tractors is rapidly increasing in Cambodia..

Plate 20. Fish are important sources of animal protein for millions of Asia's rural people.

Plate 21. Children netting ricefield ditches for small fish, crabs, and shrimps.

Dry season rice

The dry season rice area, which is fully or partially irrigated, represents about 8% of the total cultivated rice area. It is the most variable among the rice ecosystems in terms of cultivation time, method of cultivation, topography, and soil type (CIRP 1991b). Nevertheless, it is the most productive rice environment. Its productivity is associated with better water control, higher solar radiation during crop growth, and the development and cultivation of fertilizer-responsive modern varieties.

Distribution of production area

Takeo, Kandal, Prey Veng, and Kampong Cham have the highest dry season rice production area over the years, ranging from 19,000 to 42,000 ha (Table 5.2). They are followed by Siem Reap, Kampong Chhnang, and Kratie with 5,000-10,000 ha each. In 1994-95, about 68% of the dry season rice area was located in the neighboring provinces of Kandal, Takeo, and Prey Veng. In Phnom Penh, the Tonle Sap and Mekong (upper) rivers converge and then divide into the Bassac and the Mekong (lower) rivers that flow down to Vietnam. The Bassac River and the Mekong River are on the western and eastern side, respectively, of Kandal. Dry season rice production areas are along the depressions on the northeast to southeast of Takeo (inundated by the Bassac River), northwest to southwest of Prey Veng (inundated by the lower Mekong River) and depressions between the Bassac and the Mekong rivers in Kandal. Kampong Cham, Kampong Chhnang, and Siem Reap represented 22% of the dry season rice production area in 1994-95. The production sites are low-lying areas along the course of the Tonle Sap lake and river (Plate14). In Kratie, most production areas are found in the depressions along the course of the upper Mekong River.

Diversity in the dry season rice ecosystem

The main reference for this section is the baseline survey conducted by Lando and Mak (1991) in Kian Svey District, Kandal Province. While the survey is limited to Kian Svey, the diversity in dry season rice production cited in that district is typical of the diversity found in the whole country.

Dry season rice cultivation may be broadly categorized into two. The first category is the fully or partially irrigated second rice crop after the wet season production of rainfed lowland rice. There is diversity in crop-growing period, from nursery bed establishment to harvesting. The most common is from late October to late March, with nursery bed establishment starting as early as late October to mid-November. This is called early dry season crop. The seedling and vegetative stages depend on the late wet season rainfall and residual moisture while the other stages of growth depend on irrigation. Another cropping period is from December to early May. Crop establishment can start from early December to early January. This period, referred to as late dry season crop, involves the low-lying areas. The need for irrigation is expected to be greater in the late dry season crop than in the early dry season crop.

The second category of dry season rice cultivation is the partially irrigated flood recession rice. The areas are flooded for 3-5 mo before water recession takes place. These are largely the flood receding areas of very deepwater lands around lakes, rivers, and water reservoirs that are not suited for deepwater rice cultivation because water rise is too rapid. Also included are some wet season deepwater rice areas that have been converted for dry season cultivation of early-duration rice. This conversion results in higher and more reliable yield for farmers. Flood recession fields are level paddies situated on sloping areas. Sequential cultivation is conducted as water recedes. The upper fields are the first to be cultivated, being the first to experience water recession, and the lowest fields are the last to be cultivated. Staggered sowing can start as early as late October and as late as February. Harvesting is from mid-February to April. In some places, sowing is from late March to April and harvesting can be as late as the end of August, as observed in the receding areas of Srey Ampal reservoirs, Kian Svey District, Kandal Province (Lando and Mak 1991). The crop is benefited by residual soil moisture and early rains but may suffer from rising water at harvesting time.

Both the partially to fully irrigated second rice crop and the flood recession rice crop may be transplanted or direct seeded. Both have diverse field levels and consequently diverse soil fertility just like the rainfed lowland ecosystem. But unlike the rainfed lowland ecosystem where field levels correspond to different maturity classes, the dry season crop involves only photoperiod-insensitive varieties.

Production strategies

Many production strategies and practices in the dry season rice production are similar to those employed in rainfed lowland rice production. One major difference between the two is the ability to control water in dry season rice production.

Flood recession rice has the distinct characteristic of having short, staggered rice cultivation intervals. Sowing in nursery beds is done several times within 5-10-d intervals. This is essential to obtain seedlings at the correct age for serial transplanting as water recedes down the slope. Thus, different stages of rice growth can be observed over a small area.

In some flood recession areas, land preparation is done after harvest, before the floodwater rises. After the floods recede, additional tillage may be done. In Siem Reap, where the floodwater is clear, dry seed is broadcast in areas when the floodwater (10-25 cm) is about to recede in a few (usually 10) d.

Production constraints

Early-maturing modern varieties dominate dry season rice production. The national average yield for the dry season is about 2.6 t ha^{-1}, more than a ton higher than the national average yield for the wet season. It is at least half a ton higher than the national average yield of early-maturing modern varieties cultivated in the wet season. The higher productivity of dry season rice can be attributed to better water control and more solar radiation. Since water control is better, production risks are reduced, and farmers tend to apply more fertilizers. This contributes to the high yield of N-responsive modern varieties.

The dry season rice productivity in Cambodia is still lower than those in other Asian countries due to a number of production constraints. One major problem is irrigation. Most irrigation systems are inefficient because of poor design and maintenance, and this affects the quantity and timely delivery of irrigation water. Ricefields may have short aerobic periods that favor weed growth. The alternating aerobic and anaerobic conditions are conducive to nitrification and denitrification, the latter being a common avenue through which N is lost.

Dry season and wet season rices share the same pest and socioeconomic problems. Dry season rice areas, especially the flood recession areas, are generally more fertile than the rainfed lowland rice areas. However, they could still be lacking in N and P. Varietal constraints include seed source, seed purity, and quality seed. There is still a need for varieties with higher yield potential, growth duration shorter than 120 d, and good grain qualities.

Modern varieties

Considering the various times of cultivation in both the partially to fully irrigated second rice crop and the flood recession rice crop, the dry season culture spans from October to August. This long period of cultivation is made possible by the use of photoperiod-insensitive varieties which are not affected by daylengrh. These varieties mature in less than 150 d. This class of varieties is shared with the early-duration rainfed lowland rice ecosystem. The following discussion focuses on the early-duration, photoperiod-insensitive modern varieties cultivated in both dry and wet seasons.

Pre-CIAP modern varieties. Photoperiod-insensitive modern varieties developed in IRRI—IR5, IR8, IR20, and IR22—have been tested at Toul Samrong and Bek Chan stations in Batrambang in the early 1970s (Perez 1973). Because of the collapse of the research and development program in the following years, these varieties were not commercially grown (Nesbitt 1990). During the reign of Pol Pot, short-duration varieties from China were introduced. Immediately after Pol Pot's regime, 1.5 t of IR36 from Vietnam were introduced (Khush et al 1986). IRRI started sending back traditional varieties to Cambodia upon the request of the government in 1981. In the process, modern varieties like IR36, IR48, IR52, and IR54 were also introduced (Anonymous 1982).

In the mid-1980s and prior to the release of the CIAP varieties, IR36 (IR2071-625-1-252) was the most popular modern variety in Cambodia. IR36 was released in the Philippines in 1976 because of its high yield potential (5 t ha^{-1}) in irrigated lowland rice environments, short-duration (110 d), and multiple resistance to insect pests and diseases (PhilRice 1993). It was once the most popular variety in the Philippines not only in the irrigated lowland but also in the drought-prone rainfed lowland rice environment. In some provinces of Cambodia like Takeo, Kandal, and Kampong Speu, the yield of IR36 ranged from 2.0 to 3.0 t ha^{-1} in the rainfed lowlands fertilized with 30-45 kg N ha^{-1} and 1.5-4.8 t ha^{-1} in receding areas fertilized with 70 kg N ha^{-1} (Fujisaka 1988).

IR42 (IR2071-586-5-6-3) was a far second to IR36 in the 1980s in Cambodia. IR42 was released in the Philippines in 1977 as a medium-duration variety (135 d) with high yield potential and pest resistance. It had longer growth duration and was taller (110 cm) than its sister line IR36 (85 cm) (PhilRice 1993). Because of its height, it became prominent in areas in Cambodia with slightly higher water levels. Its yield was comparable with that of IR36 (Fujisaka 1988).

CIAP-sponsored varieties. The VRC released IR66, IR72, and Kru (*kru* means teacher in Khmer) in 1990 and IR Kesar (kesar means anther in Khmer) in 1993 for dry and wet Season rice cultivation. IR66 and IR72 were released in the Philippines in 1987 and 1988, respectively, for the irrigated lowland environment. However, IR66 became the most popular variety in the drought-prone rainfed lowland environments and not in the irrigated areas for which it was bred. Kru and IR Kesar, both developed by IRRI, were released only in Cambodia. IR Kesar was introduced to Cambodia through INGER as one of the entries in the International Irrigated Rice Observational Nursery in 1990.

Table 5.7 Yield, growth duration, and plant height of recommended early-duration rice varieties in advanced yield trials.

Variety	Wet season		Dry season		Duration (d)	Height (cm)
	Yield (t ha^{-1})	% YA	Yield (t ha^{-1})	% YA		
Released in 1990 [a]						
IR66	4.2	7.7	4.0	11.1	109	77
IR72	4.0	2.6	4.0	11.1	115	81
Kru	4.3	10.3	4.1	13.9	113	83
IR64 (check)	3.9		3.6	-	-	-
Released in 1990 [b]						
IR Kesar	3.5	0	4.2	-7.1	117	91
Kru (check)	3.5	-	4.5	-	-	-

[a] Data based on 25 and 6 trials in the dry and wet seasons, respectively, from 1989 to 1990 (CIRP 1989,1990).
[b] Data based on 19 and 32 trials in the dry and wet seasons, respectively, from 1991 to 1992 (CIRP 1991,1992).

IR66, IR72, and Kru were released in Cambodia because of their high yield advantage over check variety IR64 (Table 5.7). Kru had the highest yield potential and was used as the check in the testing activities that followed. IR Kesar was released a few years later (even though its yield was lower than Kru's) because of its higher resistance to brown planthopper compared with previous releases (VRC 1993). IR66 has the shortest growth duration (109 d) and IR Kesar has the longest (117 d). IR66 is the shortest (77 cm) and IR Kesar is the tallest (91 cm). All released varieties have long, slender grains.

The test entries in OFAT were IR66, IR72, and Kru from the 1990 wet season up to the 1993 dry season. The average yield of each recommended variety was substantially greater than that of farmers' best varieties, regardless of season, with IR66 giving the highest yield (Table 5.8). The yield advantage of both IR72 and Kru over farmers' varieties was comparable in both seasons. However, the yield advantage of IR66 over the check was higher in the dry than in the wet season. IR66 was the most preferred variety while the farmers' own varieties were least preferred. Aside from its high yield, a valuable characteristic of IR66 is its earlier growth duration. The shorter the time a crop is in the field, the lesser is its exposure to potential field problems.

IR66 was replaced by IR Kesar in the OFATs starting in the 1993 wet season because of the latter's popularity among farmers. IR Kesar has a higher yield than IR72 and Kru. In the wet season, it was the variety given first preference by many farmer-cooperators. However, compared with the previous set of OFATs (1990-93), more farmers gave first preference to their own varieties this time. This could be attributed to the inclusion of IR66 as the check variety. For example, in the 1994 dry season, 22 OFATs had IR66 as the local check. Its mean yield was higher than any of the test entries. By the end of 1994, IR66 had replaced IR36 as the most widely cultivated variety in shallow water lowland areas.

There were farmers who used their best photoperiod-insensitive traditional varieties as a local check. In many instances, the released varieties performed better than the traditional varieties.

Table 5.8 Yield of recommended early-duration varieties in on-farm trials and farmers' preferences, 1990-95.

Variety	Yield (t ha^{-1})		Farmers' preference (no.)			
	Wet season	Dry season	Wet season		Dry season	
			First	Second	First	Second
Set I (1990 wet season - 1993 dry season)[a]						
IR66	3.0	4.3	121	38	99	49
IR72	2.9	4.0	37	75	35	82
Kru	2.9	4.0	45	69	54	75
Local check	2.6	3.6	6	4	13	12
Set II (1993 wet season -1995 wet season)[b]						
IR72	2.3	3.9	44	86	21[c]	82
Kru	2.4	4.0	57	80	79	68
IR Kesar	2.6	4.1	126	48	78	60
Local check	2.2	3.8	31	43	36	25

[a] Set I involved 232 and 200 on-farm trials in the wet and dry seasons, respectively. [b] Set II involved 235 and 230 on-farm trials in the wet and dry seasons, respectively. [c] IR72 was tested only in 85 of 132 trials in the 1994 dry season. This could introduce bias in the comparison between IR72 and other entries.

Varietal purity. The CIAP uses pure (breeder or foundation) seed in OFATs. Thus, farmers are always impressed with the uniform stand of the released varieties. Farmers' varieties are often impure and uneven. Tall plants in a population shade the shorter plants, making them less nutrient-responsive. Likewise, plants that differ in growth duration constitute an impure stand. Management practices, such as correct timing of fertilizer applications and harvesting, become a problem when the plants differ substantially in growth duration. The quantity and quality of the harvest is reduced when immature and mature grains are harvested together. In Battambang, rice millers are paying more for pure varieties because their milling recovery is higher than when they process mixed varieties (Anonymous 1996).

Farmers commonly observe that the purity of a variety changes with time. Some causes of genetic impurity are mechanical mixture, outcrossing, residual segregation, and spontaneous mutation. The value of pure seed was demonstrated in on-farm trials conducted by the Programme de rehabilitation et d'appui au secteur agricole du Cambodge (PRASAC)-Takeo in 1995-96. IR66 seed obtained from CIAP/PRASAC was given to 10 farmers who produced their own IR66 seed. The estimated yields of the CIAP/PRASAC IR66 (pure) and the farmers' IR66 (impure) were 5.8 and 4.8 t ha^{-1}, respectively. Without changing the variety, yield was increased by about 21 %, just by using pure seed.

Varietal adoption. Although Cambodia did not experience the Green Revolution, farmers are fully aware of the yield potential of modern varieties in shallow water lowland rice areas. They are interested in trying new varieties. Those living close to the border with Vietnam even obtain IRRI varieties from Vietnamese farmers.

Modern early-duration varieties are the dominant varieties in the dry season rice area, estimated to be more than 150,000 ha. They are also cultivated in the wet season in about 100,000 ha (DA 1995). There are no available statistics on the area being occupied by the released varieties. However, it is very likely that they constitute the largest proportion of modern varieties grown because of the concerted efforts to disseminate them. First, on-farm variety adaptation trials introduce the new varieties to farmer-cooperators. If the variety is good, which is usually the case in OFATs, farmer-cooperators keep the harvest and use it in the following season. Second, the government stations and NGOs multiply and disseminate seed produced by the CIAP. The choice of variety to be multiplied is based on the demand of farmers. Third, the same government offices and NGOs conduct field days to introduce the new varieties to non-farmer-cooperators. Because the crop is being grown the whole year round, there is continuous flow of seed from the government/NGOs to farmers and from farmers to farmers. It should be noted that other varieties released in Cambodia are grown only in the wet season. Seed produced for those varieties should be stored during the dry season. The released varieties make substantial contribution to the high yields of dry season rice in Cambodia.

Breeding strategy

Variety introduction and release. The outstanding performance of varieties currently released by CIAP illustrates how Cambodia could directly benefit from breeding programs of other countries for early-duration varieties. Thus, Cambodia will continue to rely on foreign introductions for planting under favorable rice environments. This strategy will save a lot of resources and time, considering the tremendous efforts that go with the development of these varieties. For example, genes from 17 traditional varieties from six countries (China, India, Philippines, Thailand, Indonesia, and the United States) had to be combined and recombined for several generations to produce IR36 and its sister line, IR42. The gene pool from which IR66 was extracted involved 20 traditional varieties; IR72, 22 traditional varieties; Kru, 18 traditional varieties; and IR Kesar, 22 traditional varieties. Considering the wide genetic ancestry of the released varieties, it is not surprising that each can find its own place in many countries. In different countries, adoption occurs in areas that are similar—i.e., water can be controlled (prolonged drought is avoided) and addition of fertilizers is therefore less risky.

The CIAP recognizes the fact that cultivation of a single variety in a large area over the years makes it vulnerable to insect pests and disease outbreaks. Thus, it will support the continuous release of new varieties to increase the diversity among varieties recommended for farmer's use.

Seed production. One of the results of the Green Revolution was the development of the seed industry in many developing countries. The seed industry involves a partnership between the government and the private sector in seed production, certification, and distribution. The more developed the seed industry is, the more quality seed is available for farmers' use. High-quality seed is genetically pure, physiologically mature, free of diseases, insect pests, weed seeds, and other physical contaminants; and has a high germination rate. Crop productivity increases with the use of quality seed. In the Philippines, the use of high-quality seed increased the average rice yield from 3.5 to 4.4 t ha^{-1} in the irrigated lowland environment covered by the government's Grain Production Enhancement Program (Anonymous 1995).

Compared with many Asian countries, Cambodia has lagged behind not only in rice research but also in rice seed production. To hasten the spread of newly released varieties, the CIAP conducts OFATs in as many sites as possible and collaborates with government stations, international organizations, and NGOs interested in variety demonstrations and seed production.

It provides them with breeder or foundation seed. For some groups such as the PRASAC-Kampong Cham and PRASAC-Svay Rieng, on-the-job training on seed production was provided to their staff. These organizations and PRASAC-Takeo are involved in seed production in farmers' fields. Since 1995, the CIAP has conducted a 2-wk seed production training course annually for local research staff and seed farmers to strengthen their technical capability. This is in support of a forthcoming World Bank national seed project for Cambodia which aims to rehabilitate seed farms, provide seed-processing equipment, train staff in seed technology, and establish a seed production network, among other things (Anonymous 1996). Benefits from the use of outstanding varieties can be fully maximized once the seed industry is in place.

Deepwater/floating rice

Deepwater rice is grown in low-lying areas and depressions that accumulate floodwater at a depth of 50 cm or more for at least 1 mo during its growing period. Maximum water depth ranges from this depth to more than 3.0 m. The floodwater originates from the Tonle Sap Lake and the Mekong and Tonle-Bassac rivers, and their tributaries flood the low-lying areas and depressions, a portion of which is cultivated with deepwater rice. The water rise is always intensified by local rainfall.

Distribution of production area

In the late 1960s, the deepwater rice area was about 400,000 ha, representing nearly 16% of Cambodia's riceland. From 1980 to the present, it is only 4-7% of the cultivated rice area. Deepwater rice areas are located in the provinces close to the Tonle Sap Lake, the Tonle-Bassac River, and the Mekong River (Plate 15). In 1994-95, the deepwater rice areas were mainly located in Kampong Thom (31,000 ha), Banteay Meanchey (15,000 ha), and Battambang (11,000 ha). Deepwater rice areas in Siem Reap, Takeo, Pursat, Kampong Cham, and Kampong Chhnang ranged from 2,000 to 7,000 ha each. Kampong Cham, Svay Rieng, Prey Veng, Kampot, and Stung Treng had less than 1,000 ha each.

Diversity in the deepwater rice ecosystem

The growing conditions in the deepwater rice ecosystems are very diverse. These are brought about by variations in pre-flood rainfall, topography, and flooding patterns.

Pre-flood rainfall. This refers to the rains which fall before the flood and which generally occur between March and July. Timing and intensity of rainfall vary across years and locations.

Topography. Based on water depth and flood duration, deepwater rice areas can be divided broadly into two. The first category involves water depth of 50-100 cm over a period of at least 1 mo. Aside from being photoperiod-sensitive, traditional varieties grown in this ecosystem are late-maturing. Because of this, farmers classify them under *srau thngun,* the category for rainfed lowland late-duration rices. Such deepwater rice areas are hereinafter referred to as medium deepwater rice areas. In some years, maximum water depth in these areas may be lower than 50 cm; if it is 50 cm, the duration of inundation is short, satisfying the requirement for rainfed lowland rice ecosystem.

The second category involves water depth of more than 100 cm for at least 1 mo. These areas are called very deepwater or floating rice ecosystems. Varieties adapted to this condition have good elongation ability. During water recession, their culms bend horizontally on the water surface, with the top portion of the plants bending upward (kneeing ability). Plants appear to float so Cambodians refer to them as *srau laungtuk* (floating rice). They also produce nodal tillers and roots. Floating rices are sometimes called *srau via* (nodal tillering rice).

The water level is a function of the depth of the depression. This can be level to gradually sloping. In a given site, the lowest area could be a floating rice area and the highest may be suitable for medium deepwater rice. The lowest area is the first to be inundated and the last one to dry up.

Floodwater is always turbid because of the silt, clay, and organic matter it carries. In a sloping area, most of these particles are deposited in the low field. The low field is thus the most fertile and potentially the highest yielding. For example, in the Piam Montia village cluster, Kampong Trabaik District, Prey Veng, farmers reported yields of 1.3- 1.6 t ha^{-1} in the low fields, 1.2-1.4 t ha^{-1} in the middle fields, and 0.8-1.0 t ha^{-1} in the high fields during normal flooding (Lando and Mak 1994b). Farmers describe the high fields as red sandy soils; the middle fields as black sand or silt sand soils; and the low fields as black silt loam soil.

Flooding patterns. A flooding pattern is the result of the onset time of inundation, rate of water rise, maximum water depth and its duration, and time and rate of water recession. The water may start to rise between July and August. It may be gradual or rapid and maximum water depth may vary between 50 cm and more than 300 cm, depending on location. The maximum water depth is usually registered between September and November and can last for a few days or several weeks. Its recession may be gradual or rapid to a few centimeters between November and early January.

There are no available flooding pattern records in farmers' fields in Cambodia. However, in CIAP's yield trials for deepwater rice, the water level is measured every week to determine the flooding pattern in test sites. Figure 5.1 shows the flooding pattern in five testing sites for CIAP's advanced yield trial for deepwater rice in 1994. The testing sites were Day Eth (Kandal), Neak Ta Krabao (Pursat), Thnaut Kanchrung (Takeo), Trapeang Veng (Kampong Chhnang), and Prek Ambel (Kandal). At Day Eth, there was a gradual water rise from the second week of July (8 cm) to the fourth week of September (91 cm). The average rate was 1.2 cm d^{-1}. The maximum water depth was about 90 cm which lasted for nearly 3 wk. Water receded at the rate of 1.4 cm d^{-1} over a period of 7 wk. The water level at Neak Ta Krabao was about 50 cm from the fourth week of July to the third week of August and rose at the rate of 4.3 cm d^{-1} until the fourth week of September, during which the highest water depth (261 cm) was recorded. The flood-

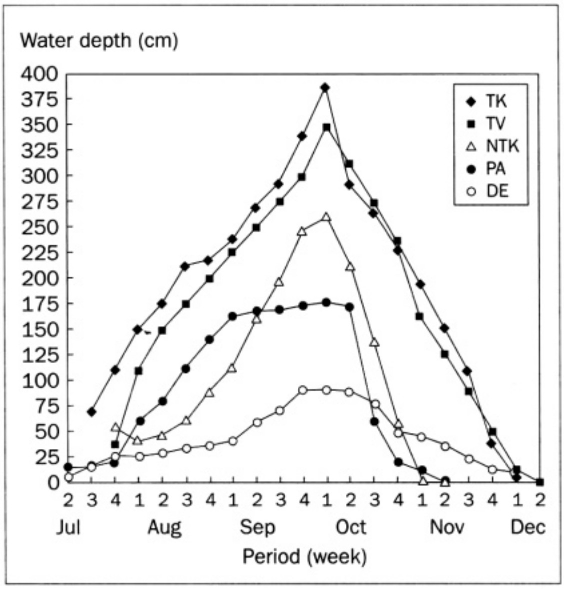


Figure 5.1 Water depth (cm) in advanced yield trials conducted at five stations.

water receded completely in the first week of November. The rate of water drop was about 9.2 cm d^{-1}. At Thnaut Kanchrung, the water level increased at the rate of 4.6 cm d^{-1} from July until the first week of October when water level was at its peak (390 cm) and dropped at the rate of 6.9 cm d^{-1} until the first week of December. The flooding pattern at Trapeang Veng was similar to that of Thnaut Kanchrung except that the water level in Trapeang Veng was generally lower. In both sites, water level was at least 100 cm for nearly 15 wk. At Prek Ambel, the water level increased from a few to 164 cm from July to the first week of September at an average rate of 3.1 cm d^{-1}. Then the water level gradually rose at the rate of 0.06 cm d^{-1} until the first week of October when maximum water level was reached (177 cm). Floodwater level dropped at the rate of 16.1 cm d^{-1} from the second to the third week of October. The above examples indicate the wide variation in flooding conditions.

In a given place, flooding pattern can vary from year to year. Figure 5.2 shows the flooding pattern at Thnaut Kanchrung for a period of 5 yr. Maximum water depth was 275 cm in 1991, 160 cm in 1992, 82 cm in 1993,390 cm in 1994, and 263 cm in 1995. The highest water levels were recorded in the second week of September in 1991, the first week of October in 1992 and 1994, the second week of October in 1993, and the fourth week of September in 1995. In 1993, water depth was at least 50 cm for more than 4 wk; in other years, it was at least 100 cm for 12-17 wk. In 1993, the flooding pattern exhibited was that of a medium deepwater rice area, while in other years, the pattern was that of a very deepwater or floating rice area.

Excluding 1992, maximum water depth in Trapeang Veng ranged from 150 to 350 cm and water depth was at least 100 cm water for 10-16 wk (Fig. 5.3), indicating a floating rice environment. In 1992, maximum water depth was only 70 cm and water level was at least 50 cm for 4 wk. This was a medium deepwater rice environment.

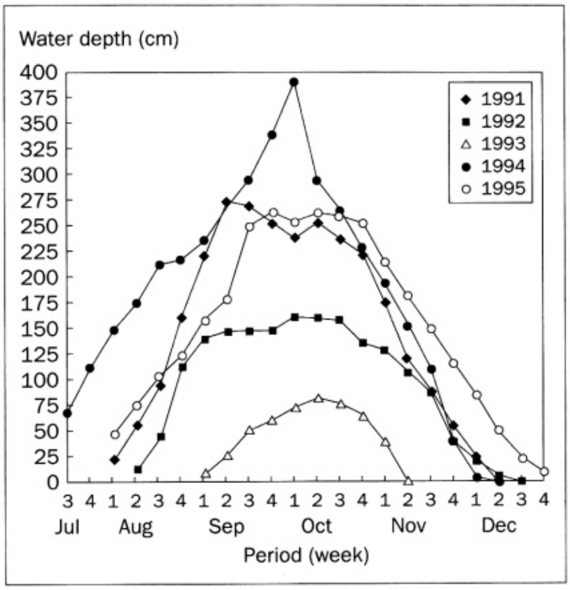


Figure 5.2 Water depth (cm) in advanced yield trial conducted at Thnaut Kanchrung, Takeo, 1991-95.

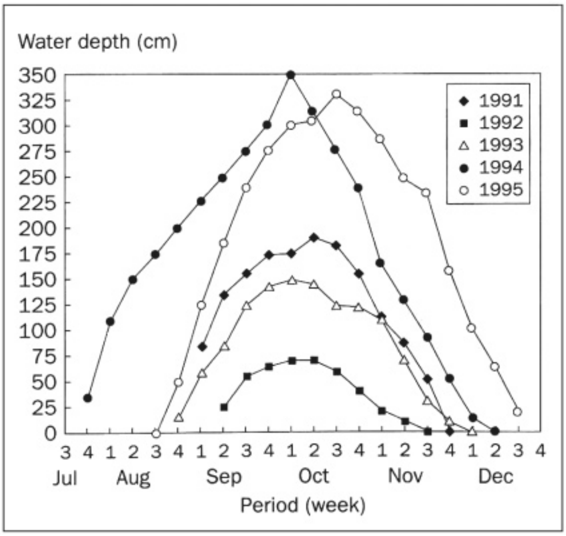


Figure 5.3 Water depth (cm) in advanced yield trial conducted at Trapeang Veng, Kampong Chhnang, 1991-95.

Figure 5.4 shows the flooding pattern at Day Eth from 1990 to 1995. The highest water level ranged from 50 cm (1992) to 118 cm (1991). The flooding pattern in 1990, 1991, 1993, and 1994 indicated a medium deepwater environment, the water level being 50-100 cm for 5-13 wk. The flooding pattern in 1992 and 1995 indicated a rainfed lowland environment. A water depth of at least 50 cm was noted in less than 4 wk.

While Thnaut Kanchrung and Trapeang Veng more often represent a floating rice environment than a medium deepwater environment, there are sites which are more often under medium deepwater than under floating conditions. Similarly, some sites are more often in a medium deepwater environment than in a rainfed lowland late-duration rice environment. Still in other areas, the opposite arrangement prevails. This complexity is a result of the unpredictable amount of water that the upper Mekong River discharges to the Tonle Sap Lake and its tributaries from year to year. With an annual maximum water level fluctuation of as much as 2 m in the Tonle Sap Lake, it is possible that some fields may be classified as a floating rice ecosystem when the maximum water level in the lake is 2 m and a rainfed lowland when maximum level is very low (Chaudhary et al 1995).

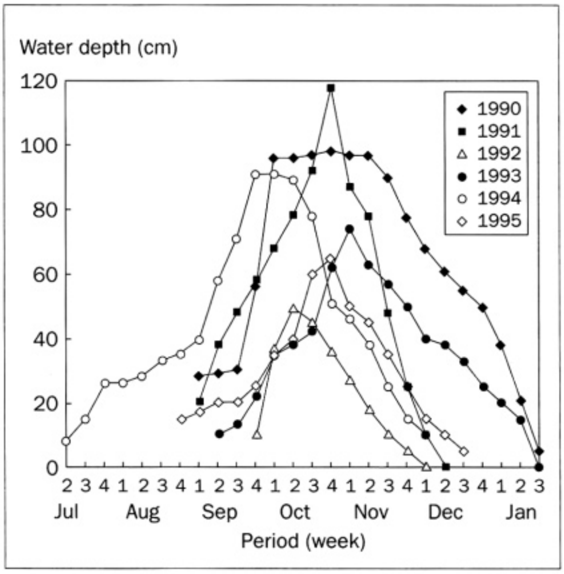


Figure 5.4 Water depth (cm) in advanced yield trial at Day Eth, Kandal, 1990-95.

Overview of production practices

The following brief description of production practices is based primarily on the observations made by Lando and Mak (1994b), Fujisaka (1988), and CIAP staff and cooperators. Production practices for deepwater rice are very simple, involving very minimal external inputs. They usually start with the burning of straw and stubble remaining in the field after being grazed by ruminants. This takes place between February and early April. The unbunded field is plowed once or twice before broadcasting dry seed. Seeding time in the southern provinces including Takeo, Prey Veng, and Kandal is from late April to May while that in the northern provinces such as Battambang, Banteay Meanchay, and Siem Reap is from May to mid-June. In general, the lowest part of a sloping deepwater rice area is the first to be cultivated, being the first to be inundated. The average rate of seeding can range from 120 to more than 200 kg ha^{-1}. The higher rate is used when the field is plowed only once. A second plowing generates better soil structure (finer soil clods and better aeration) and destroys weeds which remain after the first plowing.

Seed may be incorporated into the soil by harrowing or plowing. Tillage operations further improve soil structure and thus favor good root development. The resulting soil cover also protects the seed from birds and rats. If there is sufficient soil moisture, germination proceeds a few days after sowing. It can be delayed for weeks, depending on rainfall.

Early planting is always desired so that the crop is more mature when the floodwater comes. Older plants sustain elongation better than younger plants and are therefore flood-resistant.

Seedlings obtained from the thickly populated sections of the field are transplanted in vacant spaces when free water starts to accumulate in the paddies. Sires may be hand-weeded before flood accession. Grain maturation often coincides with water recession and the crop is usually harvested in dry fields. Harvesring takes place from late December to lare February in the southern provinces and from late January to early March in the northern provinces. Crops in the highest field sites are harvested first, usually with sickles to cut the stem about a half meter below the panicles. The length of the straw remaining in the field is directly correlated with the maximum depth of water in the area. Harvested grain may be sun-dried for 2-3 d before transporting to the threshing site which is often close to the farmer's house.

Production constraints

The deepwater rice ecosystem is characterized by low productivity. The contributing factors are lack of good varieties and low soil fertility unpredictable timing and intensity of pre-flood rainfall, onset of flooding, rate of water rise, maximum water depth, duration of maximum water depth, timing of water recession, and rare of water decline. A drastic change in any of these factors often brings about a complete crop failure Their unpredictability is the major reason why farmers employ minimum inputs in deepwater rice production.

Pre-flood rainfall. The onset and sufficiency of the pre-flood rainfall dictate the timing of land preparation and sowing. An adequare early rainfall means early crop establishment and more vigorous seedlings. When the flood arrives, mature plants are more adept at withstanding the rapidly rising water. Inadequate rainfall means drought at the early vegetative phases.

Onset of flooding. Ideally, floodwaters should begin to rise when the plants are fully established (at least 4-6 wk old) and have better elongation ability during flooding (Catling 1992). Tall plants are better adapted than short ones.

Rate of water rise. A gradual water rise ensures the survival of varieties with elongation ability. A rapid, continuous water rise can submerge even varieties with good elongating ability. Submergence retards plant growth and kills less vigorous plants at the early vegetative stages, reduces tillering at later vegetative phases, and delays panicle emergence at panicle initiation to heading, thereby causing spikelet sterility (Vergara 1985). Submergence at flowering always has a detrimental effect since at this growth stage, the rice plant can no longer elongate (Catling 1992).

Prolonged submergence (2 wk or more) kills the plants at all growth stages.

Maximum water depth. An ideal variety should flower only when the maximum water depth is reached. The flowering time of photoperiod-sensitive varieties is daylength-dependenr and therefore predictable, while the onset of maximum water depth and its duration are not. If the maximum water depth is beyond what is normal and its duration is long, there can be submergence at flowering time. This results in crop failure.

Water recession. Water recession is generally fast, often coinciding with ripening. Harvesting becomes easy when the water has completely receded. Drought after recession may follow in deepwater areas located in the high fields.

Water current. Flooding, even in the absence of submergence, can have a detrimental effect on the plant. For example, a strong current of silt-laden floodwater can damage young leaves. This type of damage causes the stand density to decrease with time. Pests, particularly rats, also contribute to stand density reduction.

Pests. Insect pests and diseases are not a major concern in deepwater rice ecosystems in spite of the 6- to 8-mo growing duration of deepwater rice varieties. During the pre-flood period, drought, low humidity and low plant density do not favor pest buildup. But even when the pre-flood period is favorable, the following flooding period is unfavorable to most insect pests (Catling 1992). However, rats contribute to significant losses during flooding. The capture of snakes and the destruction of flooded forests that house rat predators intensify the rat problem (Seng et al 1987). Birds called *plong* also cause yield reductions by trampling the crop and cutting the stems to build nests.

Varieties. The currently grown traditional varieties lack a sufficient degree of tolerance needed to attain respectable yields. This is a particular problem in areas where location-specific varieties were lost when deepwater rice cultivation was banned during the Pol Pot regime. New varieties are also required in areas where the flooding pattern was altered by the construction of water control structures.

Soil infertility. The continuous cultivation of rice over hundreds of years without sufficient replenishment of the nutrients lost results in poor soils. This is true of deepwater rice areas situated in the high fields.

Traditional varieties

Photoperiod-sensitive traditional varieties are grown in deepwater rice areas. They are likely to have a degree of tolerance for drought at the vegetative stage and are very tall with long, broad leaves. These characteristics are important during the dry pre-flood period and for weed competition. All varieries are late-maturing. Flowering time ranges from early November to early February. Varieties grown in the high fields mature earlier than those cultivated in the low fields. Seed dormancy is common among deepwater rices, ensuring that the seed will not germinate immediately after being soaked in water.

Different varieties exist for different maximum water depths and some varieties can survive in a wider range of water depths than others. However, optimum yields are obtained at a particular range of water depth for a given variety. Some examples of varietal adaptation are reported by Lando and Mak (1994b).

In Prey Kabas, Takeo, the variety Phka Mrom tolerates a water depth of 50-70 cm but not more than 1 m. Kua Kronhol and Peah Roniam are best when water depths range from 2.5 to 3.0 m, but they have severe yield losses when water depth is less than 1 m. The optimum water depth for Sambak Kraham is 1.5-2.0 m. There is yield reduction when the water level is 80-100 cm but it can survive when the water level is more than 2 m. In Piam Montia District, Prey Veng, Chmar Kombot, and Chmar Laong Tyk survive in water depths of 0.5-1.5 m but not more than 2 m. Srao Ongka tolerates a 2.5-3.5-m water depth, but there is a severe yield reduction when the water level is below 1 m.

In general, varieties grown in medium deepwater rice areas have varying degrees of submergence tolerance. Tallness is the major mechanism by which the top canopy is kept above the flood. This maintains photosynthetic activities or protects the panicles from submergence. However, some may possess weak elongation abilities.

Three characteristics that are associated more with floating rices than with rices in medium deepwater environments are good elongation ability kneeing ability, and nodal tillering (Catling 1992, Chaubey et al 1996). Internode elongation (instead of leaf sheath and blade elongation) is the critical factor during flooding Kneeing ability is another mechanism by which the plant canopy is kept above the water level in very deepwater environment. The production of nodal tillers during the vegetative stage is a good mechanism to compensate for the loss of plants/ tillers because of flooding or rat damage.

Breeding strategy

The deepwater rice ecosystem in Cambodia represents a severe multiple-stress environment. The unpredictable combination of abiotic factors controlling various stresses prevents farmers from using external inputs that can maximize yield when the environment becomes favorable. However, the probability of the environment being favorable is low. Under these circumstances, CIAP aims to identify deepwater rice varieties with improved yield and survival ability suited to different flooding patterns, along with other desirable traits mentioned in the preceding section. Stability of yield performance under varying stresses is more critical than yield.

The Cambodian deepwater rice varietal improvement program is not involved in the development of new varieties through hybridization and selection in segregating populations. Instead, efforts are concentrated on testing traditional varieties and foreign introductions. Breeding materials generated from the Huntra Rice Experiment Station and Prachin Buri Rice Research Center in Thailand are selected by Thai and Cambodian plant breeders. Some breeding lines from India, Bangladesh, Indonesia, Myanmar, Malaysia, and Vietnam are also obtained through INGER's International Deepwater Rice Observation Nursery, which is received in Cambodia every year.

The varietal testing strategy for deepwater rice differs sharply with the testing strategy for early-duration varieties for lowland environments. In the lowland ecosystem, higher inputs may be applied with reasonable risk. In contrast, varietal testing for the deepwater rice ecosystem is conducted without any additional inputs.

In 1987, IRRI started testing traditional varieties from Thailand in farmers' fields. On-station and on-farm variety trials were established in the following years. In 1991, the VRC reIeased Don, Tewada, and Khao Tah Petch. The first variety was developed in the Huntra Rice Research Station while the last two are traditional varieties from Thailand. On-farm adaptive trials for these varieties are conducted yearly to fully determine their adaptation in a wide range of environments, to allow farmers to select the most appropriate variety under local conditions, and to serve as a venue for dissemination of varieties. In many cases, the trials failed due to severe flooding and rat damage. Thus, it will take time before the impact of the released varieties are known.

Rainfed upland rice

Upland rice areas in Cambodia are unbunded fields that depend entirely on local rainfall. They are generally found scattered in rolling lands, some of which are mountainous forested areas. Thus, upland rice (*srau chamcar*) is also known as mountain rice *(srau phnom).*

The rainfed upland rice area is a small proportion of the total riceland in Cambodia. In 1994-95, the leading upland rice provinces were Ratanakiri (9,000 ha), Kampong Cham (8,000 ha), and Siem Reap (7,000 ha) (Table 5.2). Mondulkiri, Kampong Thom, Kandal, Koh Kong, Preah Vihear, Stung Treng, and Kampot had about 1,000-2,000 ha each. Smaller areas planted to upland rice could be found in other provinces. Only in Ratanakiri and Mondulkiri is the upland rice area the major rice ecosytem. In the former, the upland rice area is more than twice the area for rainfed lowland rice.

Diversity in the upland rice ecosystem

The upland rice ecosystem is very diverse in spite of the very small area it occupies. Diversity is brought about by the differences in environmental and cultural conditions under which upland rice is grown. The environmental factors contributing to the diversity of upland rice ecosystem are elevation, rainfall, and soil type. The elevation where upland rice is grown could range from 200 to 1,000 m. At high elevations where daily temperatures are lower, varieties should possess some degree of cold tolerance. Some areas are favorable in terms of water regime while others are drought-prone. The latter would require varieties with drought tolerance and good drought recovery. As in the other rice ecosystems, upland rice is also cultivated in different soil types.

Shifting cultivation. Shifting cultivation or the slash-and-burn method is the major upland rice production system in Cambodia. Forest is cleared and planted with rice for 2-5 yr before farmers shift to a new area. Farmers often return to the old upland rice site after several years of fallow. This method of cultivation is practiced in the north and northeastern provinces and in hilly, forested areas of other provinces. The main practitioners of shifting cultivation are the various ethnic minorities. In Ratanakiri, ethnic groups involved in shifting cultivation are the Phnong, Kraveth, Kreung, Preuv, Tumpoun, Lon, Kachok, and Chhray while in Mondulkiri, the ethnic groups are the Phnong, Tumpoun, Lao, Skouy, Stieng, and Rodae. In Kratie, both ethnic minorities (Phnong, Somrae, Khuy, and Stieng) and Khmers are engaged in upland rice cultivation, with the Khmers being the major group. In Siem Reap and Kampong Som, the shifting cultivators are Khmers. The ethnic groups in the highlands are bound to their religious beliefs that nature is populated by spirits that could spell the success or failure of any endeavor (White 1996). Sacrificial offerings, prayers, and feasts are part of the cycle of upland rice culture-from identifying the site to clearing the forest and from seeding to harvesting. Rituals vary from group to group. Some tribal groups mix animal blood with the seed before sowing. Others have evolved their own cultural practices. Interaction with other groups over time also expanded the group's choice of cultural practices.

A farmer may have 1-2 upland ricefields. The size of the farm may range from 0.1 to 3.0 ha and may be situated 1-10 km from his home. Upland ricefields are often far from one another; a distance of at least 1 km is common. Rarely are upland ricefields situated near a lowland ricefield.

Trees and other plants are cut, left to dry, and burned during the dry season (February to April). Seeding is between April and June. Without tilling the soil, seeds are dibbled using pointed sticks. The seeding rate ranges from 5 to 20 seeds $hill^{-1}$, the more common rate being 10 or more seeds $hill^{-1}$. Hill spacing can range from 20 to 40 cm. Closer spacing is used in an old field (less fertile) and wider spacing in a new field (more fertile). Wider spacing is used in parts of the field where rice is mixed with other crops. Missing hills may be left as such or replanted with seedlings from thickly populated hills or seeded again. Thinning is never done. The crop is totally dependent on the native fertility of the soil and it is weeded two to three times using a hand tool. Weeding (done three times) is more frequent in late-duration than in early-duration varieties.

In Ratanakiri and Mondulkiri, each farm is divided into areas where varieties of different maturity. groups are planted. It is common to grow at least two varieties that differ in growth duration. As many as seven varieties may be grown in a field. Such varieties are harvested at different times and because of this, a large storage area for the harvest is not necessary. Staggered harvesting also serves as a guarantee for controlled grain supply. It is common to grow individual varieties. However, a mixture of different varieties with more or less the same maturity is sometimes grown in a section of the farm. In Kratie, most farmers grow one variety as is the case in Siem Reap and Kampong Som.

Mature grain is harvested between August and December, depending on the growth duration of varieties planted. Two methods are used. The first is harvesting by hand-stripping individual panicles in a standing crop. Grains are then placed in a native basket carried at the back or in one hand of the harvester. The second method is cutting close to the ground or just below the panicle. In Ratanakiri, crops are hand-stripped. In Mondulkiri, hand stripping is more often associated with late-duration varieties. Early-duration and glutinous varieties are cut. Shattering varieties are harvested by hand-stripping and nonshattering varieties, by cutting the crop. In Kratie, Siem Reap, and Kampong Som. harvesting is done by cutting the crop. Threshing by foot is more common than hand threshing.

In most places, mixed cropping is practiced—i.e.. other crops are grown in the ricefield with no distinct crop row arrangement. In Ratanakiri, rice seed and other crop seed (pearl millet, maize, sesame, and cucumber) are mixed and dibbled together. In vacant spaces, maize, sweet potato, pumpkin, taro, bitter gourd, sponge gourd, bottle gourd, wax gourd, chili, eggplant, and tobacco are planted. Cassava, sweet potato, maize, papaya, and banana may be planted in the periphery of the ricefield. Some of these crops may be grown earlier than rice by more than a month. In Mondulkiri, rice is never mixed with seed of other crops before dibbling. Mixed crop stands are achieved by planting seeds of maize and certain beans at random within the ricefield. Banana, cassava, and vegetables may be grown along the borders. In Kratie, intercropping rice with rows of maize, cucumber, and ground nut is common among Khmers. Separate plots are allocated for other vegetables. This Khmer practice is being adapted by some tribal groups. These cropping systems ensure a diverse source of food for the family. In Siem Reap and Kampong Som, monocropping (pure stand of rice) is practiced. Postrice cropping is not practiced in any upland rice sites.

Permanent cultivation. In permanent cultivation, a particular area is often grown to rice every year. Farmers often have only one upland ricefield. The size of the farm can range from 0.1 to more than 1.0 ha. Upland rice farms can be contiguous, sometimes forming a large area of rice monoculture as in Kampong Cham or they may be separated by only a few hundred meters as in Kratie. In either place, they could be adjacent to fields planted to other upland crops or rainfed lowland rice. Khmers practice this type of rice culture and, unlike in shifting cultivation, their farms are often close to their homes.

A farmer in the upland rice ecosystem often grows a single variety. The land is tilled before seeding, usually between May and June. In Kratie, land preparation often involves two plowings and one to two harrowing. Furrows are made 25-40 cm apart. Farmers hand-drill the seed in the furrows. They cover the seed with a thin layer of soil using their feet. About 20 d after sowing, excess seedlings are thinned by hand and used to replant missing hills or sparsely populated areas. For farmers with lowland fields, upland ricefields are sources of seedlings for transplanting. About 30-40 d after sowing, the field is harrowed perpendicular to the furrows.

Uprooted seedlings are covered with soil. In Kampong Cham, seeds are dibbled at the rate of 5-10 seeds $hill^{-1}$. In both places, the crops are hand-weeded two to three times and inorganic fertilizer or cow manure is added to the soil. Rice is harvested from September to October, by cutting either at the panicle base or close to the ground. Threshing is done as in rainfed lowland rice. Rice straw is used as animal feed.

In Kratie, upland rice is commonly rotated with other annual crops (Plate 16). Some farmers divide the upland farm into two blocks. In one year, the first block is grown to rice and the second block is grown to other crops such as mungbean, maize, sesame, and/or tomato. In the following year, upland rice is grown in the second block and the other crops in the first. Farmers reported that weed problems are greater in a continuous upland rice culture. Some farmers plant only rice but grow mungbean after the rice is harvested. This system is dependent on the late rains. Some farmers intercrop rice and maize.

In Kampong Cham, the market demand for rice and other upland crops including cassava and sesame determines the area to be planted to upland rice. Intercropping is not practiced. No crop is planted after rice.

Production constraints

The average yield of upland rice in Cambodia is low, at about 1.2 t ha^{-1}. However, in shifting cultivation, a yield of 1.6-1.8 t ha^{-1} in mixed crops on new land is not uncommon in Ratanakiri. The same range of yields can be obtained in pure stands in Siem Reap. Since fertilizer application is never practiced, grain yields decline with continuous cropping, causing the slash-and-burn farmers to move to a new area. However, new areas for shifting cultivation will decline rapidly as the population increases and the area logged expands. This will then favor shorter fallow periods and nutrients lost through crop uptake and soil eroded will not be replaced. Forest regrowth will be slow because of the increasingly poor soil. In permanent cultivation, farmers are limited to the same piece of infertile land. Rotation with legumes every 3-4 yr will not be sufficient to improve rice productivity.

Another reason why shifting cultivation areas are abandoned after 2-3 yr of rice cropping is the increased weed population. For late-duration varieties, the area is weeded three times during the second or third rice cropping, compared with weeding twice during the first rice cropping. Because of the depletion of native soil fertility and the acidic nature of Cambodian soils, the competitive ability of traditional rice varieties against certain weeds could be reduced over time.

Fungal diseases such as brown spot and blast appear to be common in upland rice. Disease severity is dependent to a great extent on the amount of humidity around the plant canopy and this can be reduced by wider spacing. Insect pests observed include stem borers, rice bugs, grasshoppers, and ants. There are no available reports to confirm whether insect pests and diseases are major threats to upland rice production. However, it is possible that permanent cultivation is more prone to higher insect pest and disease incidence than shifting cultivation. Permanent cultivation is more or less a monoculture, involving a large area of riceland where pests can multiply. In shifting cultivation, upland rice farms are situated some distance away from each other, and the forest which separates them serves as a barrier to insect pest migration and pathogen dispersal. However, in areas where deforestation is substantial, pests may become a serious problem with the destruction of the habitats of alternative hosts for predators.

Rats, rabbits, wild pigs, deer, and squirrel are known to damage upland rice, with the first three considered as a major problem. These pests are controlled using traps and fences. The most common birds that cause problems are parrots, pigeons, wild pigeons, and sparrows. They eat dibbled seeds and ripening grain. Birds are controlled manually by scaring them away.

Mixed cropping is common under shifting cultivation. Certain crop combinations have been known to reduce insect pest and disease incidence. Farmers reported that sesame grown with rice has less pests than the pure stand of sesame. There is also substantial genetic diversity in shifting cultivation as a result of planting several single and mixed varieties in a small piece of land. This indigenous practice prevents epidemics inasmuch as varieties differ in their levels of resistance to biotic stresses. Genetic diversity also prevents a shift in pathogen races or insect pest biotypes.

Drought is also a problem in rainfed upland areas. It can occur at any stage of growth. Severe drought at the early growth stages can devastate the crop. Thus, ethnic people always keep a sufficient amount of seed for two seedings, in case the first one fails. Early-duration varieties can escape late drought, and late-duration varieties could be subjected to drought at the reproductive stage. Therefore, planting both at the same time reduces the risk of crop failure.

Traditional varieties and breeding direction

Only traditional varieties are grown in the upland rice areas. They have a wide range of maturities similar to rainfed lowland rice. In general, they have long culms, long and droopy leaves, and few tillers. The height and leaf characteristics enable them to compete better with weeds. The long, droopy leaves form a good soil cover and thus contribute to soil moisture conservation. The high straw yield supports raising of ruminants. Tall varieties make harvesting by hand-stripping easy since farmers do not have to bend. In general, traditional varieties have a certain degree of drought tolerance and a good ability to recover after drought.

While the upland rice area is very small in comparison with other ecosystems, the morphoagronomic variability of traditional upland rice varieties is great. This is due to the diverse environments/cultural practices employed in its cultivation, each of which may require different varietal characteristics. For example, varieties grown at high elevations should have a higher degree of cold tolerance than those grown at lower elevations. Harvesting by hand-stripping favors selection of varieties with high shattering ability while the practice of harvesting panicles followed by threshing favors a nonshattering type. Awnless varieties are easier to strip by hand than awned ones. It is likely that some upland rice varieties are better than others in pure stand (equal competitive ability for light, water, and nutrients) or mixtures (unequal competition). Seedling vigor and rapid vegetative growth are critical characteristics for varieties being used in mixed cropping.

In 1991, the VRC approved the release of two improved upland rice varieties which were developed by the International Institute for Tropical Agriculture and evaluated by CIAP. Called Sita and Rimke, these varieties have high yield potential in pure stands and are early-maturing. The latter trait reduces the risk of being subjected to drought. The high yield potential is associated with erect leaves and responsiveness to fertilizer applications. They are shorter than the traditional varieties. Because of their leaf orientation and short stature, these varieties are less competitive against weeds and against traditional varieties in mixed stands. The potential for adoption is thus highest in areas under permanent cultivation. The number of OFATs conducted for this system, however, is limited and it is not yet known if these varieties will be adopted by farmers.

CIAP, in collaboration with the SDC Rice Biodiversity Project, IRGC, and IRRI is currently collecting traditional upland rice varieties in the less accessible, mountainous areas of Cambodia. These collections will be characterized and scored in gene banks. Promising varieties will be purified and tested in farmers' fields.

The ethnic people in the highlands have their peculiar method of cultivating upland rice. They are capable of adopting new technology within the context of their culture. In Kratie, the Khmer method of upland rice culture has been adopted by some tribal groups. In Ratanakiri, some ethnic groups such as the Chhray and Tempun also culltivate lowland rice in addition to upland rice (White 1996). This was the result of their interaction with ethnic Khmers during the Pol Pot era and with the present government staff. Conducting trials and introducing new varieties require the assistance of social scientists who must assess how the trials and the new varieties fit into the culture of the ethnic minorities.

Cited references

Anonymous. 1982. lRRI germplasm bank returns traditional rice seeds to Kampuchea. IRRI Reporter. Manila (Philippines): International Rice Research Institute.

Anonymous. 1995. Seed growers now have places to go for registered seed. PhilRice Newsl. 8 (5):6-7.

Anonymous. 1996. A country in need of a national seed program. Asian Seed 3 (3): 4-7.

Catling HD. 1992. Rice in deep water. Manila (Philippines): International Rice Research Institute. 542 p.

Chaudhary RC, Hillerislambers D, Puckridge DW. 1995. Improvement of deepwater rice varieties for Cambodia: a vertical and lateral support model. Plant Varieties Seeds. 8:175-185.

Chaudhary RC, Sahai VN. 1993. Collecting, evaluation, and conservation of Cambodian rice germplasm. FAO/ IPGRI Plant Genet. Resour. Newsl. 96:59-63.

Chaubey CN. Dwivedi JL, Gregorio GB, Mendoza R, Mishra SB, Palaklang W, Patena CC, Puckridge DW, Quillon CC, Senadhira D, Thakur R. 1996. Breeding flood-prone rice. 'Thailand-IRRI Collaborative Program for Improving Flood-prone Rice. Prachinburi (Thailand): Prachinburi Rice Research Institute. 116 p.

[CIAP] Cambodia-IRRI-Australia Project. 1993. Annual research report 1993. Phnom Penh, Cambodia. 206 p.

[CIAP] Cambodia-IRRI-Australia Project. 1994. Annual research report 1994. Phnom Penh, Cambodia, 251 p.

[CIRP] Cambodia-IRRI Rice Project. 1989. Annual research report 1989. Phnom Penh, Cambodia. 324 p.

[CIRP] Cambodia-IRRI Rice Project. 1990. Annual research report 1990. Phnom Penh, Cambodia. 324 p.

[CIRP] Cambodia-IRRI Rice Project. 1991. Annual research report 1991. Phnom Penh, Cambodia. 324 p.

[CIRP] Cambodia-IRRI-Rice Project. 1991a. Rice production in Cambodia. Phnom Penh, Cambodia. 45 p.

[CIRP] Cambodia-IRRI Rice Project. 1992. Annual research report 1992. Phnom Penh, Cambodia. 388 p.

Department of Agronomy. 1995a. Rice production area in 1994-95 dry season. Paper presented at the agriculture meeting, on 11 Jul 1995, Department of Agronomy, Ministry of Agriculture, Forestry and Fishery, Phnom Penh, Kingdom of Cambodia.

Department of Agronomy. 1995b. Rice production area in 1995 wet season. Paper presented at the agriculture meeting, 15 Nov 1995, Department of Agronomy, Ministry of Agriculture, Forestry and Fishery, Phnom Penh, Kingdom of Cambodia.

Department of Planning and Statistics. 1993. Bulletin of Agricultural Statistics and Studies. Phnom Penh, Kingdom of Cambodia: Ministry of Agriculture, Forestry and Fishery and Rome, Italy: Food and Agriculture Organization.

Fujisaka S. 1988. Rice agroecosystems, farmer management and social organization in Kampuchea: a preliminary assessment and research recommendations. IRRI Res. Pap. Ser. 136. 16 p.

[IRTP] International Rice Testing Program. 1988. Standard evaluation system for rice. Manila, Philippines: International Rice Research Institute.

Khush GS, Puckridge DW, Denning GL. 1986. Trip report to People's Republic of Kampuchea, 3-30 Jan 1986. Manila, Philippines: International Rice Research Institute

Lando RP, Mak S. 1991 , Srey Ampal: a baseline survey of dry season rice in Cambodia. IRRI-Cambodia Project. 96 p.

Lando RP, Mak S. 1994a. Rainfed lowland rice in Cambodia: a baseline survey IRRI Res. Pap. Ser. 152. 20 p.

Lando RP, Mak S. 1994b. Deepwater rice in Cambodia: a baseline survey. IRRI Res. Pap. Ser. 153. 29 p.

Lando RP, Mak S. 1994c. Cambodian farmers' decision making in the choice of traditional rainfed lowland rice varieties. IRRI Res. Pap. Ser. 154. 17 p.

Makara O, Chaudhary RC, Javier EL. 1995. Conventional and innovative strategy of rice breeding for rainfed lowlands of Cambodia. In: Fragile lives in fragile ecosystems. Proceedings of the International Rice Research Conference, 13-17- Feb 1995. Manila, Philippines: International Rice Research Institute. p 855-864.

Nesbitt HJ. 1990. Cambodia's national rice research system—starting from scratch. Paper presented at the American Crop Science Society Meeting, San Antonio, Texas, USA.

Ministry of Environment (RGOC) and United Nations Development Programme. 1994. Cambodia: first stare of the environment report 1994. 315 p.

Perez AT, 1973. Report of trip to the Khmer Republic, 6 Dec 1972-5 Jan 1973. Manila, Philippines: International Rice research Institute.

Philippine Rice Research Institute. 1993. Rice production technoguide. Department of Agriculture, Maligaya, Muñoz, Nueva Ecija.

Rickman JF, Pyseth M, Sothy O, Theavy KC, Sokha N. 1995. Farm mechanization and crop production in Cambodia. Phnom Penh, Cambodia: Cambodia-IRRI-Ausrralia Project. 20 p.

Sahai VN, Chaudhary RC, Sovith S. 1992. Rice germplasm catalog of Cambodia. Phnom Penh. Cambodia: Cambodia-IRRI Rice Project.

Sahai VN, Chaudhary RC. Sovith S. 1992a. Rice germplasm catalog of Cambodia II. Phnom Penh. Cambodia: Cambodia-IRRI Rice Project.

Seng TS , Puckridge DW, Thongbai P 1988. Cultivation of deepwater and floating rice in Kampuchea. In: Proceedings of the 1987 International Deepwater Rice Workshop, Bangkok, Thailand. Manila. Philippines: International Rice Research Institute. p 159-167.

Vergara BS. 1985. Growth and development of the deepwater rich plant. IRRI Res. Pap. Ser. 103. 38 p.

[VRC] Varietal Recommendations Committee. 1993. Proceedings of the VRC meeting. 9 Mar 1993. Phnom Penh, Kingdom of Cambodia: Department of Agronomy: Ministry of Agriculture, Forestry and Fishery.

White J. 1996. Highlanders of the Cambodian northeast. PSRA Cambodia Rep. 2 (1): 7-10.

Pest management in rice

G. C. JAHN, KIEV BUNNARITH, PHENG SOPHEA, AND POL CHANTY

More than 60 species of weeds and 200 species of arthropods have been identified from Cambodian ricefields (CIAP 1995). Most of these arthropods are not phytophagous (i.e., plant-eating) but are scavengers, predators, and parasites. The most important pests in each ecosystem are listed in Table 6.1.

Rainfed lowland rice pests

Broadleaf weeds, grasses, and sedges all cause problems in Cambodian rainfed lowland rice. Weeds within this ecosystem are particularly difficult to eradicate because of the inability to control the water level in the fields. Rarely are crops continuously flooded throughout the season. Exposure of the soil surface, coupled with high soil moisture, encourages weed germination. Dirty dora, also known as umbrella sedge (*Cyperus difformis*), is the most commonly reported weed in Cambodian lowland rice (Table 6.1).

The most common wet season defoliators (i.e., leaf eaters) are small caterpillars called green semiloopers (Noctuidae: *Naranga* spp.) (CIAP 1995). Although they are numerous, semiloopers and other caterpillars do not usually have an impact on rice yields. During the first 30 d after transplanting, a rice plant can lose up to 50% of its leaf area without any resulting yield loss if the flag leaf is not cut (K. Heong, IRRI, pers. commun.).

The most common wet season predators are semiaquatic veliid bugs (Veliidae: *Microvelia douglasi* Scott) and spiders (Table 6.2).

While Cambodia has a high diversity of natural enemies of rice pests, the ecological balance sometimes tips in favor of the pests because the rice plant does not have adequate water or fertilizer. For example, brown planthoppers are usually not pests, unless the natural enemy populations are disrupted by pesticides. In Svay Rieng, however, a rainfed crop may be without standing water for most of the season. Without semiaquatic predators, the brown planthoppers build up higher than their normal number, resulting in hopperburn. The inability to manage water levels effectively contributes to many lowland rainfed rice pest problems. Grasshoppers do not usually affect yields in continuously flooded fields, but when an initial heavy rain is followed by 1 or 2 mo of dryness, grasshoppers then become a pest. Likewise, the caseworm is easily controlled by draining a field for 2-4 d. But farmers with caseworm problems are often reluctant to drain the water from their fields because they do not have the means to put it back, and they cannot always depend on the rain. If newly transplanted rice is drained and left without water for more than a week, crickets or grasshoppers will frequently eat the seedlings. Draining fields for caseworm control works best if the land has been leveled; otherwise, caseworms survive in the puddles (Plate 17).

Table 6.1 Major Cambodian rice pests in the four main rice ecosystems.

Ecosystem	Animal pests	Weeds	Diseases
Rainfed lowland rice	Birds Brown planthoppers Caterpillars (army worms, cutworms, greenhorned caterpillars, caseworms, rice skippers, semiloopers) Crabs Crickets Gall midges Golden apple snail Grasshoppers Green leafhoppers Rats Rice bugs Stem borers	Broadleaf weed (*Monochoria vaginalis*) Grasses (*Brachiaria mutica, Ischaemum rugosum, Leersia hexandra, Panicum repens*), *Echinochloa crus-gall, Paspalum distichum* Sedges (*Cyperus difformis, Eleocharis dulcis, Fimbristylis miliacea*)	Bacterial blight Bacterial leaf Streak blast Brown spot Leaf blight Leaf scald Narrow brown spot Sheath rot Sheath blight Tungro?[a]
Upland rice	Grasshoppers Rats Rice bugs Stem borers	Broadleaf weed (*Alternanthera sessilis*) Grasses (*Cynodon dactylon, Echinochloa colona, Ischaemum rugosum*) Sedges (*Cyperus rotundus*)	Blast[a] Brown spot
Deepwater rice	Rats Stem borers[a]	Broadleaf weed (*Ipomoea aquatica*[b], *Monochoria vaginalis*[b]) Grasses (*Echinochloa colona*[c], *Leersia hexandra*[d]) Sedge (*Cyperus difformis*[c]) Wild rice	Unknown
Dry season irrigated rice	Birds Brown planthoppers Caterpillars (caseworms, cutworms, greenhorned caterpillars, leaffolders) Golden apple snail[e] Grasshoppers Rats Rice bugs Stem borers	Grasses (*Echinochloa crus-galli E. colona*) Sedge (*Cyperus difformis*)	Tungro?[a] Blast Brown spot

[a] Unconfirmed reports. [b] Found in deepwater rice after flooding has occurred. [c] Before flooding and during the early stages of flooding, this plant is a weed in deepwater rice. [d] Can compete with rice under dry or flooded conditions. [e] A newly introduced pest, which is expected to become serious over the next few years.

If rainfall is sufficient for caseworms, it is usually sufficient for gall midge (GM) as well. In the dry season, GM live as inactive prepupa in weeds. They become active when the monsoon begins. If there are cloudy skies, high humidity, and drizzling rains, GM populations will build

Table 6.2 Major natural enemies of rice pests in Cambodia.

Natural enemy	Type	Prey or host
Spiders (Arachnida: Araneae, e.g., orbweavers, wolf spiders, sac spiders)	Predator	Planthoppers, leafhoppers
True bugs (Insecta: Hemiptera, e.g., mirid bugs, *Cyrtorrhinus lividipennis;* semiaquatic bugs, *Microvelia douglasi*)	Predator	Planthoppers, leafhoppers
Beetles (Insecta: Coleoptera, e.g., ladybird beetles)	Predator	Aphids, mealy bugs, scales, caterpillars
Earwigs (Insecta: Dermaptera)	Predator	Mealy bugs
Dragonflies and damselflies (Insecta: Odonata, e.g., *Agriocnemis*)	Predator	Mosquitoes, gnats, midges, flies
Wasps (Insecta: Hymenoptera: Braconidae, Mymaridae, Eupelmidae, Trichogrammatidae, Scelionidae, Eulophidae, Platygasteridae, Pteromalidae)	Parasite	Planthoppers, leafhoppers, caterpillars, gall midges, stem borers
Flies (Insecta: Diptera: Pipunculidae)	Parasite	Planthoppers, leafhoppers
Twisted-winged parasites (Insecta: Stresiptera)	Parasite	Planthoppers, leafhoppers
Nematodes	Parasite	Planthoppers, leafhoppers
Meadow grasshopper (*Conocephalis longipennis*)	Predator	Stem borer eggs
Frogs	Predator	Flies, mosquitoes, midges
Birds	Predator	Crickets, grasshoppers and virtually any insects except those under ground, inside rice plants, or under water; also eat rats; snails; other birds
Fish	Predator	Mosquitoes, planthoppers, leafhoppers
Snakes	Predator	Rats

up (Wongsiri et al. 1971). Two local rice varieties, Kaun Trei and Changkom Kreal, are more susceptible to GM damage than other Cambodian rice varieties. Normally, more than 90% of GM are parasitized in any given field. With such high rates of parasitism, insecticides are not recommended for GM control. Insecticides would kill parasitoids and result in GM outbreaks in the long run. Biological control by itself is not necessarily sufficient for GM management. The variety of rice grown is also an important consideration. This was vividly demonstrated in a CIAP study where three rice varieties that suffered the most GM damage had GM populations that were more than 97% parasitized (Table 6.3). An integrated approach to GM management, combining biological control with varietal resistance, is the best strategy. The biological control agents are already in the ricefield (Table 6.2). To preserve the natural enemies of GM, farmers need only to avoid applying insecticides. Rice varieties IR36 and IR42 are GM-resistant and available in Cambodia. A CIAP nationwide survey of more than 1000 lowland rice farmers indicates that most farmers are aware of GM damage, but they do not know the cause.

As in GM management, varietal resistance is an important factor in stem borer management. Most traditional rice varieties have reduced yields at only one whitehead per hill. However, the total number of tillers damaged by stem borers usually does not exceed 2% in a given field. The potential for stem borer damage is generally greater in traditional varieties than in modern rice varieties because most traditional varieties cannot compensate for the lost tillers. A number of modern varieties are moderately resistant to certain stem borer species. There are at least four species of stem borers found in Cambodian rice: *Scirpophaga incertulas* (Walker), *Chilo auricilius* Dudgeon, *Chilo suppressalis* (Walker), and *Sesamia inferens*

Table 6.3 Percentage of gall midge damage among 10 different traditional rice varieties and percentage of gall midge parasitized on those varieties 55 d after transplanting. Toul Koktrap Station, Svay Rieng, 1994 wet season.

Variety	Damage (%)	Parasitism (%)
Kaun Trei Khmao	11.2	97.9
Changkom Kreal	9.1	97.2
TS - 2[a]	6.0	100.0
Sak Gneuk	5.6	95.1
Phcar Sla	3.5	92.8
Kantuy Touk[a]	3.1	100.0
Sac Nang	2.2	92.3
Srau Kol	2.1	95.8
Neang Minh Toun	0.5	98.3
Changkom Ropeak	0.3	90.9
Mean ± SE	4.38±1.09	96.04±0.96

[a] Although 100% of the gall midge collected were parasitized, gall midge inflicted damage before being killed by parasitoids. Source: CIAP 1995.

Table 6.4 Composition (%) of stem borer species in rainfed lowland rice at 30, 55, and 80 DAT. 1994 wet season.

Province	Yellow stem borer (*Scirpophaga incertulas*)	Gold-fringed stem borer (*Chilo auricilius*)	Striped stem borer (*Chilo suppressalis*)	Pink stem borer (*Sesamia inferens*)
		30 DAT		
Kandal	62.8	27.9	9.3	0.0
Kampong Speu	59.5	28.6	11.9	0.0
Svay Rieng	52.4	38.1	9.5	0.0
		55 DAT		
Phnom Penh	45.0	35.0	12.5	7.5
Takeo	43.2	43.2	4.5	9.1
Kandal	51.0	31.0	13.8	3.5
Kampong Speu	54.3	40.9	2.9	1.9
Svay Rieng	55.1	30.8	5.6	8.5
		80 DAT		
Phnom Penh	50.0	28.9	13.2	7.9
Kandal	61.4	31.4	2.9	4.3
Kampong Speu	63.6	27.3	0.0	9.1
Svay Rieng	60.0	36.0	0.0	4.0

(Walker). The yellow stem borer (*S. incertulas*) and the gold-fringed stem borer (*C. auricilius*) are the most common stem borers throughout the wet season in every province surveyed (Table 6.4). IR36, IR42, IR66, and IR72 are the rice varieties available in Cambodia with reported resistance to stem borer. However, no rice variety which is completely resistant to all stem borer species has been identified. IR36 is moderately resistant to yellow stem borer and resistant to striped stem borer, while IR42 is susceptible to yellow stem borer and moderately resistant to striped stem borer.

In contrast to stem borers, there is currently no apparent need to develop varietal resistance to green leafhoppers (GLH) or to the tungro virus which GLH can transmit. During the wet season, 12-60% of GLH are parasitized, depending on the region. Why parasitism is higher in some areas than in others is unknown. Preliminary research results suggest that rice variety is not a factor. Parasites appear to keep the Cambodian GLH populations at low and nondamaging levels. Since GLH populations apparently do not attain the high levels necessary to affect yields simply by feeding, the only concern is their transmission of tungro virus. There are few confirmed cases of tungro in Cambodia (Azzam 1996), though there are many unconfirmed reports. Tungro symptoms, characterized by stunting and orange leaf tips, are difficult to distinguish from symptoms brought about by nutrient deficiencies and water stress, a common situation in Cambodia. An immunological test, such as the enzyme-linked immunosorbent assay, is required to positively identify the presence of tungro.

The presence of some other rice diseases has been confirmed (Table 6.1). Brown spot is the most common disease, followed by narrow brown spot. Both are fungal diseases. Brown spot has been found in all 12 provinces surveyed. The highest incidence of brown spot is in Kampong Cham, Kampong Speu, Prey Veng, and Takeo. Brown spot incidence is relatively low in Kandal. Leaf scald, another fungal disease, has been found only in Kandal, and in less than 3% of the fields (Elazegui et al 1992). Given the small amount of data collected so far, it is premature to make recommendations for disease control. Recommendations for disease management must be tested under different environmental conditions at a number of sites. Mew et al (1986) point out that there are no standard procedures for disease management in rainfed lowland rice culture because the systems are so diverse that no single procedure can be applied to all of them. Within Cambodia, diversity is great indeed. Some rainfed rice varieties receive insufficient water and others receive excess water. Soil composition varies across the country (CIAP is in the process of developing a soil classification system). Land preparation varies with region and economic status of rice farmers. There are more than 2,000 rice varieties in Cambodia, each with its own unique degree of susceptibility and resistance to a range of diseases. Use of resistant varieties is probably the most economical method of disease control for Cambodia, but more research is required before specific varieties can be recommended for specific regions. A number of weeds found in Cambodian rainfed lowland rice are known to harbor rice pathogens in other countries. It would therefore be prudent to remove weeds.

Upland rice pests

As in the lowlands, rain is a limiting factor in upland rice production. Generally, weeds start to germinate earlier than upland rice. Weed competition occurs 4-9 wk after sowing rice (Gupta and O'Toole 1986). Since upland rice does not have standing water to suppress weed growth, weed competition here is more intense than in lowland rice. The problem is compounded because upland weeds may germinate throughout the year. Important upland weeds are listed in

Table 6.1. Some of these weeds withstand drought better than rice. Upland ricefields are dibble-seeded, which delays weeding because it is difficult to tell grassy weeds from rice in the early growth stages. Poor soils limit weed growth to some extent. If fertilizer is applied before weed control, the excess weed growth can decrease yields, particularly if traditional upland rice varieties are grown. Planting high-yielding, fertilizer-responsive, semidwarf rice varieties allows farmers to use fertilizers in the upland ecosystem (Gupta and O'Toole 1986). Sita (1TA257) and Rimke (ITA150) are high-yielding upland varieties available in Cambodia. However, upland farmers who cannot afford the fertilizer applications may be better off using the traditional varieties. The traditional varieties are taller and can probably compete with weeds better than the semidwarf varieties on poor soil.

Potassium-poor upland soils, as in the lowlands, are associated with brown spot. Brown spot, a fungal disease characterized by the presence of oval brown spots on the leaves, infects rice at all growth stages. Fungal diseases increase in severity as the humidity of the microclimate increases. Broadcasting rice creates a canopy that encourages fungi in spite of the fact that the field is without standing water.

The lack of standing water makes upland rice prone to grasshopper infestations. Flooding and plowing a field immediately after harvesting will destroy grasshopper eggs in the soil, preventing outbreaks the following season. This control method is not possible in upland rice because no water is available for flooding. If grasshoppers attack in the early stages of a crop, their effect can be devastating. Grasshoppers can eat entire fields of newly germinated rice. On the other hand, grasshopper infestations at the milky stage or later do not usually result in large yield losses. Because the insects are large and obvious, grasshopper outbreaks are generally reported. In contrast, rice bugs frequently go unnoticed, though they have the potential to decrease yields since they feed directly on developing grains in upland and lowland fields.

Deepwater rice pests

Very little research on crop protection has been conducted in Cambodian deepwater rice. No insect pests or diseases of major importance are known in Cambodia. Rats and weeds are probably major pest problems. Deepwater rice has some of the weeds found in the other three ecosystems, as well as some unique weed species (Table 6.1). During the early crop stages, dryland weeds invade the field. These are replaced by aquatic weeds when the field is flooded. Seeds of dryland and aquatic weeds are always present in deepwater rice areas, so preventive measures, such as removing or killing all weeds before planting are necessary.

Likewise, rats are always present in deepwater rice-growing areas. Rats are a pest throughout the life of the crop. They can swim quite well and even build nests in flooded fields.

Dry season irrigated rice pests

Of the four rice ecosystems, irrigated rice is the only ecosystem with adequate water control. Water control is especially important for preventing semiaquatic weeds. Healthy, transplanted rice in a properly prepared field has a head start on weeds. All upland weeds can be eliminated from irrigated rice through water management. Grasses and sedges are the only weeds that appear to pose problems in Cambodian irrigated rice (Table 6.1). Rats, birds, and stem borers are the major animal pests in this ecosystem.

Direct seeded rice is more susceptible to pests than transplanted rice. This is because root anchorage is poorer and lodging is more serious in direct seeded rice. Competition between rice and weeds is more serious in direct seeded rice since rice and weeds emerge together. This also limits the range of useful herbicides available. Less labor, however, is an advantage of direct seeding.

The golden apple snail has recently been introduced to Cambodia. It has the potential to inflict tremendous damage in irrigated, continuously flooded rice. The snail is only a pest for about the first 3 wk after transplanting. Transplanting older seedlings and getting them established quickly decrease the potential for snail damage.

Tungro is the most commonly reported disease by farmers of irrigated rice. But green leafhoppers, which transmit tungro viruses, are rarely reported as pests. This suggests that the yellow-orange leaves have another cause, possibly a nutrient deficiency. Immunological assays which could confirm the presence of tungro virus have been used in Cambodia (Azzam 1996). After tungro, fungal diseases are regarded by farmers as the worst disease problem in irrigated rice. Resistant varieties offer the best hope for managing fungal diseases, but more research is needed before recommendations can be made.

New crop protection problems

Golden apple snails

Golden apple snails (*Pomacea* sp.) of South American origin were discovered in Cambodia in August 1995. These snails are a potential threat to rice production. They have significantly reduced rice yields in Taiwan, the Philippines, Thailand, and Vietnam. In each of these countries, the snails were raised by the people as food (Plate 18). In each country, the snails escaped to become rice pests, while those raising golden apple snails lost money because people are not eager to eat them. The same situation in Cambodia prevails, where the snail is being raised in at least nine provinces.

Golden apple snails produce bright pink or red egg masses around grass, sticks, rice, or anything extended above water in the fields. They will also lay their eggs on the sides of cement jars or basins. If the eggs are broken, a blood-red liquid is released. Snails begin life quite small, roughly the size of this "o" immediately after hatching. Eventually they grow to have shells 6-8 cm in length. The shells vary from brown to amber. The native apple snails (*Pila* sp.), which do not eat rice plants, have shells that are brown, black, or dark green. They are not considered rice pests. The differences between the golden apple snail and the native apple snail are presented in Table 6.5.

The golden apple snails in Cambodia are potential rice pests and should be destroyed. Transplanting older seedlings helps reduce snail damage. The vegetative stage of the rice crop is the most vulnerable to snail damage. The egg masses can be collected and crushed. Placing bamboo stakes around the field gives the snails a place on which to lay eggs, making egg collection and destruction easier. Snails must be hand-picked in the morning and afternoon when they are active. The snails collected can be eaten by ducks and pigs. If completely cooked, the snails are fit for human consumption. Snails can also be controlled by herding ducks through ricefields immediately after harvest or 30-35 d after transplanting early-maturing rice, or 40-50 d after transplanting late-maturing rice.

Table 6.5 Differences between the golden apple snail and the native apple snail.

Characteristic	Golden apple snail	Khmer apple snail
Shell color	Yellow, amber, or brown-black	Dark green to black, sometimes with an amber sheen
Body color	Yellow	Black
Operculum (the trap-door-like shell underneath)	Flexible	Brittle
Shell morphology	An open spiral, the shell can be easily placed on a pencil point	A closed spiral, shell cannot be balanced on a pencil point
Eggs	Pink or red; laid above water on sticks, vegetation, or rocks	White; laid underneath aquatic plants or underwater in soil
Diet	Rice seedlings, vegetables, algae	Algae

Pesticides

So far, only rice farmers in the lowlands have been interviewed on their pesticide use habits. While herbicides are used in some provinces, insecticides and rat poison are, by far, the most commonly used pesticides in the country. Of those farmers using pesticides, 69-100% use insecticides depending on the village. Fungicide use is extremely rare. In both wet and dry seasons, farmers applying insecticides use about half a liter per hectare per application. Wet season farmers generally apply insecticides during one or two crop stages (tillering and stem elongation); while dry season farmers generally apply insecticides during three or four crop stages (tillering, stem elongation, booting, and heading). About 40-100% of dry season farmers and 8-50% of wet season farmers use pesticides, depending on the province. Nationwide, there are

Table 6.6 Pesticide use in Cambodia.

Province	Farmers surveyed (no.)	Wet season (WS)		Dry season (DS)	
		Farmers (%)	Farmers using pesticides (%)	Farmers (%)	Farmers using pesticides (%)
Kampong Cham	100	100	16	8	88
Kampong Chhnang	120	99	8	25	50
Kampong Speu	111	100	11	40	40
Kandal	118	92	20	20	65
Prey Veng	121	90	12	34	71
Siem Reap	107	100	33	68	49
Svay Rieng	126	93	50	11	100
Takeo	118	90	13	44	54

1.5-12.5 times as many wet season farmers as dry season farmers (Table 6.6). Most of the farmers using pesticides are men (71-100%).

At least 30 different insecticides are available in Cambodia. The World Health Organization (WHO) classifies pesticides into three groups, with category I being the most hazardous. The most commonly used pesticides in Cambodian rice are in the WHO Hazard Class I. In most provinces, methyl parathion is the most common pesticide used. The class I pesticides available in Cambodia are listed in Table 6.7. These pesticides should not be used by farmers to control rice pests.

Table 6.7 Class I Insecticides available in Cambodian markets.[a]

Commercial name	Trade names	Chemical type	Producer
Aluminium phosphide	Delisa	Inorganic	UK
Carbofuran	Furadan	Carbamate	Vietnam
Dichlorvos	DDVP	Organophosphate	Thailand, Vietnam
Endrin	Endrin	Organochlorine	Thailand
Methamidophos	Methaphos, Monitor, Fillitox	Organophosphate	Thailand, Vietnam, Germany
Methomyl	Methomyl	Carbamate	Thailand
Methyl-parathion	Parathion-methyl, Folidol, Fosintol-phodetol, Isodol D	Organophosphate	Thailand, Vietnam
Mevinphos	Triphos, Phosdrin	Organophosphate	Thailand
Monocrotophos	Azodrin, Mobile 600	Organophosphate	Vietnam, Thailand

[a] These insecticides are classified by the World Health Organization as being the most dangerous to human health. The insecticides listed in this table should not be used for rice pest control.

Cited references

Azzam O. 1996. Trip report to Vietnam and Cambodia, 21 Sep-l Oct 1996. Manila (Philippines): International Rice Research Institute.

[CIAP] Cambodia-IRRI-Australia Project. 1995. CIAP annual report: 1994. Phnom Penh: CIAP.

Elazegui FA, Rapusas HR, Teng PS, Nesbitt HJ. 1992. Assessing the prevalence of rice pests in Cambodia. Int. Rice Res. Newsl. 17(6):26-27.

Gupta PC, O'Toole JC. 1986. Upland rice: a global perspective. Manila (Philippines):International Rice Research Institute.

Mew TW, Shahjahan AKM, Mariappan V. 1986. Diseases and disease management of rainfed lowland rice. In Progress in rainfed lowland rice. Manila (Philippines): International Rice Research Institute.

Wongsiri TP, Vungsilabutr, Hidaka T. 1971. Study on the ecology of the rice gall midge in Thailand. In: Proceedings of the symposium on tropical rice, 19-24 Jul 1971, Tokyo, Japan. p 267-290.

Farm mechanization

J. F RICKMAN, MEAS PYSETH, AND OM SOTHY

Cambodian rice producers have a long tradition of using farm machinery in the production of rice. A larger area was plowed by four-wheel tractors in the 1960s than today, tractor and truck assembly plants were then operated, and most of the larger towns had active foundries and manufacturing workshops.

Today, most advances in mechanization are occurring in the labor-intensive operations associated with land preparation and crop threshing in the rainfed areas of the northern provinces, the floating rice areas along the Tonle Sap and Mekong rivers, and the dry season irrigated areas in the south.

Land preparation

Most of the rice-growing land in Cambodia is cultivated by farmers using a pair of animals and the traditional moldboard plow and harrow. While it is very difficult to estimate the total area plowed using mechanized power, the 1992 statistics indicate that at least 240,000 ha (approximately 12%) of Cambodia's rice-growing area is plowed with four-wheel tractors and three-point linkage disc plows (Plate 19). Contractors using both animals and tractors complete approximately 20% of the first plowing and 10% of second plowing and harrowing.

In the southern rainfed lowland areas, majority of the fields are plowed using a pair of animals when the soil is wet or flooded. This normally occurs in May or June. The soil is plowed to a depth of 70-100 mm and, depending on soil conditions, a second plowing may occur 1-3 mo after the initial working. Fields are normally harrowed immediately after the second plowing. If the seed is to be broadcast, this will occur after the second plowing and prior to harrowing. In the northern provinces around Battambang, dry plowing normally begins in early May after which the seed may be broadcast. The fields are then harrowed and seed is left to germinate with the onset of the wet season.

In floating rice areas, fields are plowed dry from February to May. Fields are normally plowed by tractors using either 3- or 7-disc plows to a depth of 70-100 mm. Depending on soil tilth and rainfall, a second plowing may be done. In most instances, the seed is broadcast dry and then harrowed to give a soil coverage of 10-20 mm. Where the soil is not cultivated by harrows or plowed after broadcasting, birds and rodents eat a large percentage of the seed.

In the irrigated areas, the soils are often more friable and easier to work because of higher soil moisture content. When a tractor is used, the fields are plowed with a disc plow to cut up and incorporate stubble to a depth of 100 mm. When animals are used, the fields are worked as soon as possible after harvesting or, if the soil is dry, the fields may be flooded prior to working. Following plowing and flooding, the soil is then tilled using harrows. In areas where two crops are grown per season, only one plowing is done after the first crop. Tractors are preferred as the task can be accomplished much faster.

Many of the problems associated with water and crop management occur because of poor cultivation practices and uneven fields. Fields are often left very rough with many large clods, some areas unworked, and large cut-out furrows in the middle of the field. These problems appear to be more prevalent where tractors with three-disc plows are used for dry plowing.

Power source

Animal plowing. Oxen or buffalo are still the most popular power source for land preparation and transportation. There are presently more than 1.6 million draft animals working in Cambodia and each pair of animals is capable of plowing between 0.2 and 0.25 ha d^{-1}. The average farm area worked per pair of animals is 2 ha, with a maximum of 5 ha in some districts. One pair of oxen/buffalo can be purchased for $300-400. Buffalo are preferred in the irrigated areas as they are considered to be stronger than oxen. Traditional moldboard animal plows cost approximately $25 each.

Four-wheel tractor plowing. Four-wheel tractors have been widely used in Cambodia since the late 1950s. The Massey Ferguson tractor company had an assembly plant in Sihanouk during the 1960s and reports at that time showed that more than 500 tractors were operating in Battambang Province alone. Today, four-wheel tractors are widely used in the northern rainfed areas in Battambang and Banteay Meachay provinces, where more than 120,000 ha are cultivated annually, the floating rice areas along the Tonle Sap and Mekong rivers, and the dry land irrigated areas in Takeo Province. Since 1985, nearly 2,000 units ranging in size from 45 to 60 kW have been imported from Russia. It is estimated that approximately 1,200 of these tractors are still being used for plowing mainly by contractors. Each tractor farms between 150 and 200 ha of land with an annual usage of approximately 500 h yr^{-1}. At least 50 new units of Russian (Belarus) and Chinese (Jiangsu) 30-60-kW tractors are sold each year in Phnom Penh. A small second-hand market exists for tractors sourced from Japan and Thailand (Kubota and Iseki). These tractors range in size from 15 to 30 kW. Individual owners use their tractors for approximately 10% of the time on their own farms and contract the remainder of the usage at $10-20 ha^{-1} depending on the locality. Work rates during plowing range from 0.75 to 1.5 ha h^{-1}. The smallest field size where the larger tractors are used is approximately 0.2 ha. Power per unit area figures range from 1.8 to 2.7 ha kW^{-1}.

Repair and maintenance of tractors is a major problem. Spare parts have to be either fabricated locally, imported from Vietnam, or taken from other tractors. Front tires have been replaced with small truck or car tires, some of which are produced locally. All rear tires are imported with the majority coming from Vietnam. Tire life is approximately 1500 h or 3 yr.

Table 7.1 Cost and work rates for different power sources.

Power source		cost ($)	Work rate (ha d^{-1})	Contract rate ($ ha^{-1})
Animal	(pair)	400-500	0.2-0.25	10-15
Walking tractor	(7-11 kW)	1,000-3,500	0.8-1.2	10-15
Second-hand tractor	(17 kW)	3,000-4000	1.0-1.6	10-15
	(60 kW)	5,000-8000	5.0-8.0	10-20
New tractors	(60 kW)	11,000-28,000	5.0-8.0	10-20

Hand-held walking tractors. More than 1,300 hand-held tractors were imported from Japan, Thailand, and China. While these machines have a work capacity about 4-5 times a pair of draft animals, very few units are still operating in Cambodia. Farmers complain that these machines require as much energy to operate as traditional methods and their versatility especially for transport has never been realized.

The cost and work rates for different power sources are presented in Table 7.1.

Planting

All rice crops are manually planted by either transplanting or broadcasting. The planting techniques used by farmers depend on the locality as well as on the rice ecosystem. They include

- transplanting from a nursery,
- broadcasting presoaked seed onto wet or flooded soil surface without incorporation,
- broadcasting the seed dry and then incorporating by either plowing or harrowing while the soil is still dry (in some instances, the seed is not incorporated after broadcasting), and
- broadcasting 100-300-mm-long seedlings into fields covered with water.

Transplanting

More than 70% of the rice is transplanted from nurseries. Nurseries take 15-20% of the total farming area and are normally prepared for planting in April-May, if water is available. Care is taken in the preparation of a nursery seedbed to attain a finely prepared, level surface which is free of weeds and well drained. More than 80% of farmers apply animal manure to the nursery. Seed may be soaked for 24 h before broadcasting onto a wet soil surface. Per nursery, seeding rates vary from 500 to 800 kg ha^{-1}, depending on locality.

Seedlings are grown for varying lengths of time in the nursery before transplanting. Local varieties are transplanted after 40-80 d while IR varieties are transplanted after 20 d. Seedlings are normally transplanted 20 cm apart, but these distances may be increased to 25-30 cm in the more fertile areas. In some sandy soils, transplanting must be done within hours of harrowing, or else the soil becomes too hard. In other areas where there has been insufficient rain, transplanting is undertaken in nonflooded soil by using a stick. In the Alumisol soils of Svay Rieng, farmers will wait 2-3 d before transplanting as the soil is too soft.

Pulling and transplanting of seedlings is very labor intensive. Depending on soil type, 1 ha of rice will require between 30 and 40 person-days to establish. A number of different mechanical transplanters from IRRI, Japan, and China have been tried, but none have proven successful.

Broadcasting

Rice plants are established in the field by three different broadcasting techniques. In the northern provinces, 70% of the rainfed lowland rice area and nearly all of the deepwater rice areas are sown by broadcasting dry seed. The seed is normally harrowed into the soil after the second plowing but in some areas it is left on the surface. Germination occurs following rain or flooding.

Where seed is broadcast in the irrigated areas, more than 60% is pregerminated. Farmers soak the seed for 24 h and drain them for another 24 h prior to broadcasting onto a wetted soil surface. In some irrigation areas, seedlings are broadcast post-germination (seedlings are 100-300 mm long).

The desired number of plants established ranges from 40 to 50 plants m^{-2}. To achieve an acceptable level of establishment, allowances are made by the farmer for the rice ecosystem, the tilth of the seedbed, and the level of seed incorporation to be implemented. Seeding rates vary between 80 and 150 kg ha^{-1}. Some transplanting is normally undertaken within the field, after establishment, to even up plant stands.

In the northern provinces, 70% of farmers second-plow their fields when the crop is 30-40 cm tall. Second plowing is done to control weeds and initiate tillering. Broadcasting reduces the labor requirement for planting to less than 2 person-days ha^{-1}. Mechanical planters have not been used by farmers for crop establishment. A number of combine drills and other direct seeding machines have been imported, but inappropriate design and lack of support technology have restricted further adoption.

Pest management

Weed control

Some form of weed control is practiced by more than 60% of the farmers and of these, 20% use a combination of control measures. Nearly 50% of the farmers manually weed their fields and 6.0% use chemicals. On average, farmers spend 15 d ha^{-1} weeding their crops and 1 d ha^{-1} applying herbicides. In Battambang, more than 70% of the farmers use second plowing as a weed control measure and 15% use herbicides. The most common herbicide used is 2,4-D amine.

Pesticides

Rodenticides are the most commonly used pesticide in Cambodia. In Kandal, Battambang, and Kampong Cham provinces, more than 20% of the farmers manually apply zinc phosphate as a rodenticide. Some farmers in the irrigated areas use mechanical barriers made from woven palm leaves to protect their crops from rats. Rat trapping is an additional source of revenue in some districts.

More than 10% of the farmers use insecticides in their fields. Farmers in Kandal and Svay Rieng provinces are the largest users. In Kandal Province, which is a large vegetable producer, 29% of farmers use insecticides. In Svay Rieng, which is close to Vietnam, nearly 20% of farmers use insecticides. Molluscicides are more commonly used in the northern provinces.

Less than 2% of farmers own knapsack sprayers. The remainder either use home-made, plunger-type sprayers or use a brush to flick the chemical at the target.

Fertilization

Some form of fertilizer is applied by more than 80% of the farmers to either their nurseries or their fields. All fertilizers are applied manually. Farmyard manure is transported by animal-drawn carts during the dry season and dumped in strategic piles in the fields. Spreading is done by water movement and during land preparation.

Inorganic fertilizers are hand-broadcast and, where necessary, incorporated by harrowing. Complete fertilizers are usually incorporated while urea is topdressed. Farmers in the northern provinces tend to use less fertilizer than those in the southern regions. Farmers take 4-5 d ha^{-1} to apply manure and 1 d ha^{-1} to apply inorganic fertilizers. No mechanical fertilizer spreaders are presently being used in Cambodia.

Irrigation

Eight percent of the rice-growing area in Cambodia is irrigated in the dry season. The majority of irrigation is found in Kandal and Takeo provinces where 20% of the farmers irrigate a second crop. Supplementary irrigation is also applied by many farmers to secure their rainfed crop. In a recent survey by Rickman et al (1995), more than 10% of the farmers surveyed had irrigation pumps. Commonly used pumps include the centrifugal, long-barrel, axial-flow, and smaller propeller-type pumps. Many farmers also use the traditional manual pumps. In some areas, tubewells are becoming popular.

Harvesting

Cutting

Crops are manually harvested at moisture contents above 25% and tied into sheaves. These sheaves are placed on top of the standing stubble or transported to a central threshing site where they are dried for 2-3 d. Depending on locality, threshing is done at a central site in the field or in the village. When the rice is threshed in the village, the straw is stored for later use as animal feed or as compost. Straw left in the field is normally burned prior to the first cultivation.

There are no mechanized cutting or gathering machines used in the field.

Threshing

Grain is removed from the panicle in a number of ways. The following techniques are used by Cambodian farmers:

1. Sheaths are laid on the roadway so they are run over by passing vehicles.
2. Hand-threshing is done using a board against which the stools are hit.
3. Threshing is done on a hard floor using either animals or machines to walk or drive over the stools; the dislodged grain is then collected.
4. Mechanical threshers which may be powered by foot pedals or engines are used.

Mechanical threshers. Mechanical threshers are used in many provinces, especially in areas closest to Vietnam and Thailand. More than 250 engine-powered threshers are used in 200-250,000 ha of ricefields in Cambodia. The most popular and cheapest thresher is the Vietnamese design which accounts for at least 90% of all threshers in Cambodia. Other threshers used are the IRRI and Thailand peg tooth threshers.

The design of the Vietnamese thresher is a little different from the traditional peg tooth thresher in that the drum is proportionally longer and the pegs have been replaced with fewer but larger angled blades. Depending on the size of the thresher, there are normally 4 rows of blades

Table 7.2 Comparison of costs and capacities of different crop threshers.

Thresher	Cost ($)	Capacity (t ha^{-1})	Cost t^{-1} h^{-1} ($)
Vietnam	2000-3000	1-2	1670
IRRI (peg tooth)	2500-3000	0.8-1.5	2390
Thailand	5000-6000	2-3	2200

with 3-4 blades per row. The major advantages are its low power requirement, ability to throw straw, and ease of repair. The Thailand threshers are very popular with contractors. These machines are truck-mounted and easily transportable. They have much higher threshing capacities than other designs because the truck engine is used as the power source. This machine also has good straw-throwing capabilities. While this design incorporates a traditional peg tooth drum and wire concave, it also has a repeat auger that feeds uncleaned grain back into the drum, thus reducing labor costs and increasing efficiency.

The costs and capacities of the different threshers are presented in Table 7.2.

Grain handling and storage

Depending on moisture content, grain is often dried for 2-3 d after threshing. This drying is done on mats or other flat surfaces. Grain is transported and sometimes stored in 50-100 kg hemp or plastic bags as paddy. Ninety-five percent of the grain is stored in or under the house in small silos or vermin-proof sheds. Grain is sold to merchants and millers immediately after harvest. Most of the rice kept for family consumption is milled by a village miller who generally keeps the bran in lieu of payment. Polished grain yields vary from 55 to 60%.

Labor requirements

The total labor requirement per hectare depends on the level of mechanization and the locality. Farms that rely totally on manual labor require between 110 and 130 person-days ha^{-1} to grow a rice crop. On a highly mechanized farm, this figure can be halved. Transplanting and crop cutting can account for 50% of the total labor used on a farm.

The average labor requirements for different operations surveyed in five provinces are presented in Table 7.3.

Table 7.3 Average labor requirements for farm operations.

Operation	Manual labor (d ha^{-1})
Tillage	
1st plowing	6.1
2nd plowing	6.0
Harrowing	2.5
Sowing	
Broadcasting	1.5
Seeding/ transplanting	33.3
Fertilizing	
Manure	4.7
Granular (urea, complete)	1.0
Weeding	15.6
Harvesting	
Cutting	25.5
Threshing	12.3
Transporting	5.6

Farm machinery manufacturers

Cambodia has an association of farm machinery manufacturers but only the manufacturers of forestry equipment derive a large proportion of their income from the production of agricultural machinery. There are two shops that have manufactured threshers on consignment and at least eight very large manufacturing shops are capable of large-scale production. There are a number of foundries in Phnom Penh which have pour capacities ranging from 100 to 1000 kg. One foundry is producing aluminum plow shares for animal-drawn plows. Prices for cast iron products range from \$1 to \$2 kg^{-1}, depending on the complexity of the job. Aluminum castings are normally twice the cost of cast iron. Most furnaces are coke-fired. One provincial-owned foundry in Battambang produces spacers and bearing houses for disc plows. This foundry has a pour capacity of 300 kg and is presently averaging 7 pours yr^{-1}.

Capture and culture ricefield fisheries in Cambodia

R. GREGORY AND H. GUTTMAN

Ricefield capture fisheries

The fish that inhabit the lowland ricefields of Cambodia and other rice-growing areas of Asia are extremely prolific. They appear each year seemingly from nowhere and populate areas which, a few weeks before, had been completely dry; the small pockets of water that remained are fished continually by fishermen. These fish and other aquatic animals such as crabs, shrimps, edible insects, and frogs are important sources of animal protein for millions of Asia's rural people (Plate 20). Data collected by the Asian Institute of Technology/Department of Fisheries in Svay Rieng suggest that virtually all rice farming households in the province regularly collect fish and other aquatic produce from their fields. A study in Svay Theap District has shown that average per capita consumption of wild fish and other aquatic animals caught from ricefields and adjacent swamp areas was 31.6 kg over a 7-mo period. At this time, virtually no fish or other aquatic products were bought. Despite the obvious dependence of many rural communities on foraged aquatic products from ricefield fisheries, they appear to have been seriously neglected by researchers so far.

The fish in Cambodia's ricefields can be broadly classified into two types: white fishes, which are small herbivorous or planktivorous cyprinid species, and black fishes, which are mostly carnivorous, air breathers able to survive under low (or no) dissolved oxygen conditions. Table 8.1 lists the common indigenous fish species found in Cambodian ricefields. Both groups produce

Table 8.1 Indigenous fish species commonly found in Cambodian ricefields.

Common name	Genus	Khmer name	Feeding habit
White fishes			
Danios	*Rasbora*	*trey changvar*	Planktivorous
Barbs	*Puntius*	*trey chupin*	Herbivorous
Gouramis	*Trichogaster*	*trey cantor,*	Herbivorous
		trey kumpleang	Herbivorous
Half-beaks	*Xenentodon*	*trey phtong*	Insectivorous
Black fishes			
Snakeheads	*Channa*	*trey phtuwa trey roch*	Piscivorous
Catfishes	*Clarius*	*trey undaing*	Omnivorous
Spiny eel	*Mastacembelus*	*trey chloing*	Omnivorous
Climbing perch	*Anabas*	*trey greyng*	Omnivorous
Swamp eel	*Fluta*	*unthong*	Omnivorous

large numbers of eggs and fry at the onset of the rains which are quickly dispersed over the growing flooded ricefield area[1]. The white fishes tend to show no parental care after egg laying, and the females produce a vast number of eggs relative to their body weight. Many of the black fishes exhibit parental care by both or one of the parents and so produce fewer, larger eggs. Under confined conditions, black fish juveniles will often exhibit cannibalistic tendencies.

The exploitation of ricefield fisheries

Rice farmers employ different and ingenious methods to catch ricefield fish and other aquatic animals. These include netting, hooking, trapping, harpooning, cutting by knife, throwing nets, and gaffing. Farmers use different methods for different species during each of the three seasons.

During the wet season, fish are caught as they come out of refuge areas or move between ricefields, especially after periods of heavy rain. Machine-made, small mesh nets are now used between ricefields to catch even the smallest fish and shrimp and the growing use of these nets is likely to be detrimental to the ricefield fishery as a whole (Plate 21). Thai rice farmers report that fish caught at this time of year carry spawn, ensuring a higher market price for the fish. Farmers go out at night to trap migrating fish and spear fish and frogs, using lights to immobilize the prey. In Cambodia, there appears to be no ownership of the fish by individual land owners during this period, and people are free to take fish from any ricefield that they choose. If there is a pronounced short dry season during the monsoon, which is often the case in southeast Cambodia, this will result in immature fish being caught from the drying ricefields. Farmers in Svay Rieng often collect these immature fish for stocking their ponds. Fish typically caught at this time of year are *Rasbora* sp., small catfish and snakeheads, climbing perch, and *Puntius* spp. Nearer river systems, other species such as halfbeaks, *Mystus* spp., *Mastocembalus* spp., and riverine cyprinids may also be caught from ricefields.

During the cool season, when the ricefields begin to dry, fish are caught as they start to migrate from the fields back to the deeper water areas. This migration appears to be stimulated by the onset of the northerly winds which characterize the cool season in Cambodia. The catch usually consists of medium-sized *Clariads* and snakeheads, *Rasbora* spp., spiny eels, and anabantids. Shallow trap ponds and depressions dug in the ricefields are drained manually and the fish are caught by hand. Again, it appears that in Cambodia, open access exists for anyone wishing to catch fish in this situation. Dry jump traps also are prepared at this time of year. This technique uses a bamboo screen to block the fish's migration. Fish, especially snakeheads, are caught in the dry pit once they have attempted to jump over or around the bamboo obstruction. Fish which escape entrapment try to move to deeper locations where they can survive until the next rains. Deeper ponds dug by farmers exploit this instinct, persuading the fish that they have reached a safe area where they can survive throughout the dry season. These trap ponds are usually >3 m deep and will have one embankment broken, linking the pond to the surrounding field or a canal. Many of the ponds dug through the FFP (or through similar programs in Cambodia) have been converted for this purpose.

---

[1] It is thought that the most important factor affecting the productivity for these systems may not be the number of brood fish which survive through the dry season to breed but the extent of the distribution of the seed of those fish which survive. Wetter years will generally result in wider dispersal of seed, less crowded feeding areas. less cannibalism and predation, and higher overall fish yields.

Although few ricefield fish are usually available during the hot season, the deeper trap ponds holding the fish which had migrated during the previous cool season, are regularly netted for household consumption, then finally pumped dry, and the remaining fish caught by hand from the mud. Only at this point are the fish considered the property of the owner of the water resource. The final catch is usually only black fish- e.g., snakeheads and catfish with occasional anabantids and eels. Most white fish will have been eaten by the predatory fish under these confined conditions and are usually not present in any number in the catch at this time. Other water bodies, including the refuge areas, are fished very intensely at this time of year, usually by manually drying shallow sections of any remaining water bodies in the ricefield or, in deeper water, netting by seine or bag nets. During the period, frogs and crabs are dug up or hooked from their burrows in ricefield bunds.

This exploitation can be shown in the schematic diagram in Figure 8.1.

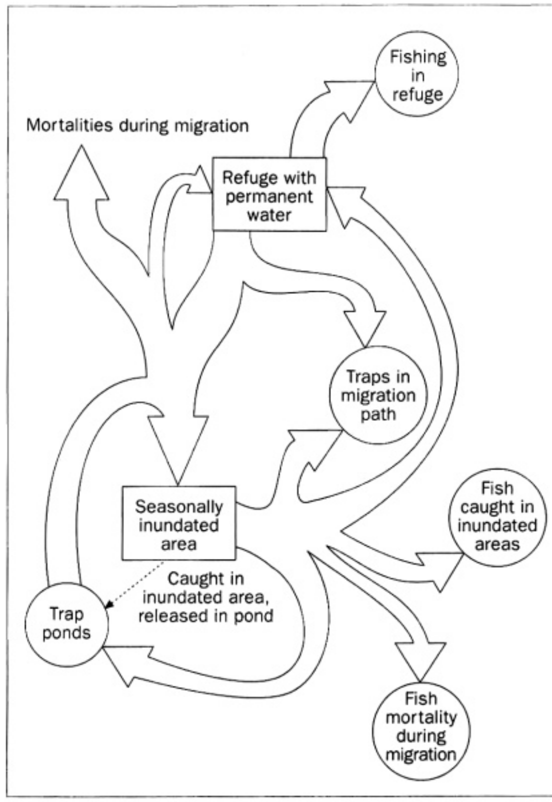


Figure 8.1 Schematic outline of the exploitation of fish in ricefield fisheries.

Fish production from ricefields and trap ponds

Annual catch rates from trap ponds vary considerably from area to area and from year to year. In drier years, lower catches from ricefields and trap ponds are to be expected. In a wetter year or a year with early and late rains, ricefields and trap ponds will likely produce more fish. Farmers in northeast Thailand report that early rains are the single most important factor in determining subsequent wild fish production.

It is difficult to estimate production of fish and other aquatic species per area of ricefield due to the transient nature of the stock and the fluctuating hydrology. Spiller (1985) suggests that 25 kg ha^{-1} may be appropriate for ricefield fish production in Thailand; in other Asian countries, the range is thought to be from 1.5 to 84 kg.

There appears to be very limited production from the trap pond itself. Fish catches from FFP size trap ponds, (80 m^2) vary from 2 kg in dry areas to 75 kg in wetter areas. Research in Kompong Ro District of Svay Rieng has shown that trap pond catches are related to land topography, with most fish being trapped in basin areas receiving drainage from extensive rice-growing areas. Larger trap ponds in Kompong Ro have been shown to yield in excess of 300 kg of fish. The increasing number of new trap ponds in many areas is likely to result in declining fish yields from individual trap ponds, although their effect on overall fish production is uncertain. This trend seems likely to continue as on-farm, dry-season water resource remains one of the best investments a farm family can make.

Trap pond data collected from Kompang Ro show an average decline in trap pond catches of 30-40% over the period 1992-95. Research carried out by AIT/DOF in the area has also shown that it is possible to zone areas according to trap pond production on a square meter basis. An example is illustrated in Figure 8.2.

The highest fish production from trap ponds in Kompong Ro is found in lower areas (3-4 m) closer to perennial water bodies, particularly in those which topographically form a basin. Zone 1 areas are characterized by being higher (>5 m) and draining to other areas.

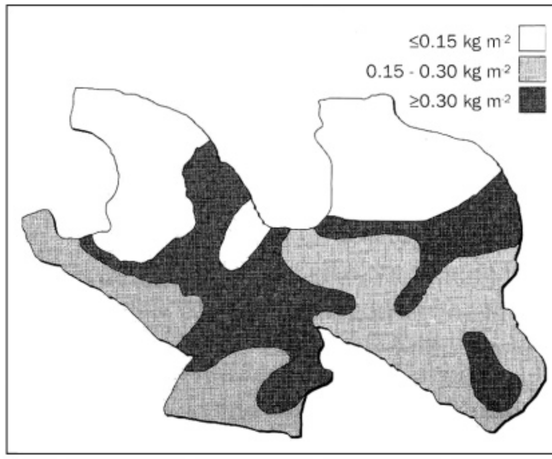


Figure 8.2 Trap pond harvests, Kompong Ro District, Svey Rieng. 1992-93.

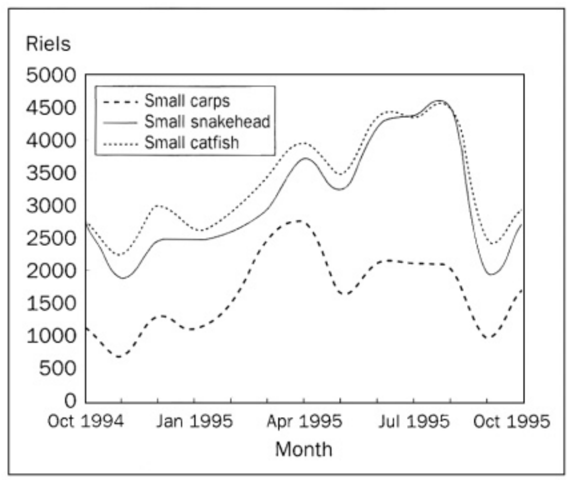


Figure 8.3 Fish prices in Svey Rieng market, Oct 1994-0ct 1995.

The species composition of trap pond catches has been shown to be quite consistent in Svay Rieng, with snakehead typically accounting for 25-40% of the total catch weight, *Clarius* catfish for 35-40%; climbing perch, 10-15%; and *Rasbora* sp., 10-15%. The predominantly black fish are very easily marketed as they can be carried live to (and back from, if necessary) the market place and they fetch a considerably higher price than cyprinids. Many Cambodian farmers try to keep their trap pond fish until Khmer New Year, when they can be sold at a higher price or when the family might like to celebrate. Figure 8.3 shows Svay Rieng market prices for three categories of fish during 1994-95.

Despite limitations imposed by location on fish productivity from trap ponds, Cambodian farmers are able to increase the number of fish that they trap through simple management methods. An example of this is putting in branches which attract and provide shelter for the fish. Mud from perennial swampy areas can also be introduced to the trap pond to persuade the fish that they have indeed reached a safe refuge area. Buffalo or cow skin introduced to the pond is used by many farmers to attract catfish and eels; feeding of rice bran to the fish is carried out by some Cambodian farmers. Household latrines are sometimes found over trap ponds.

In the Svay Theap and Kompong Ro districts in Svay Rieng, broodstock catfish and snakeheads are retained in the pond following harvest and encouraged to spawn with the first rains. Some farmers induce these fish to breed through the manipulation of water levels and the digging of burrows for the fish. Many farmers believe that the young, which spawn in a pond, will return to that exact same pond as adults. While the homing instinct in some species of fish is very precise, it is not known whether this is the case for catfish and snakeheads.

Future of ricefield fisheries

The ricefield fisheries of Cambodia and other countries in Asia appear to be extremely robust, staying productive despite the enormous fishing pressure on them. Even in the most populous countries, such as Bangladesh, it is possible for farmers to catch ricefield fish and trap fish in ponds in many areas. In Cambodia, where population is relatively small and natural resources are extensive, ricefield areas should be able to produce ample wild fish for consumption and sale in the foreseeable future. However, there are pressures on ricefield fisheries which may well result in declining fish production.

The reclamation of swamp lands for dry-season agriculture will most likely reduce the number of fish surviving in dry-season refuges each year. Associated pesticide use with dry-season rice in these areas may either kill the fish in nearby swamps or affect their ability to grow or reproduce. In many parts of Asia, such as in central Thailand, increased rice production has almost certainly been paid for by the loss of wild fish and other aquatic animals from farmers' fields.

Any increase in fishing pressure on the dry-season fish refuge is likely to result in lower ricefield fish catches in the following wet season. Any ricefield fisheries conservation measure should first concentrate on protecting dry-season refuge areas.

The use of fine-mesh nets during the early wet season to catch immature fish as they migrate between ricefields is probably detrimental to the fishery as a whole. If these nets were static, then they may constrain the free movement of fish on the floodplain. Roads, built without culverts, affect the migration of wild fish onto the floodplain and thus reduce the distribution of seed. Culverts, if they exist, are very popular places for fishing.

The move toward selling trap pond fish and the availability of pump sets will put increased pressure on fish stocks as farmers look forward to harvesting their trap ponds more efficiently and earning more money. This is becoming the case in southeast Cambodia, where trap pond fish are sold to middlemen for the Phnom Penh market. In northeast Thailand, fish catching teams operate in the lowland areas. After finding an appropriate pond, they estimate the fish stock[2], and then offer to buy the whole catch from the farmers' pond. The pond is then pumped and the fish taken to the market in a pick-up truck.

Finally, over the last 10 yr, there has been a devastating disease of ricefield fish (particularly *Channa* spp.) in Asia. Epizootic ulcerative syndrome was first reported in Cambodia in 1984, having spread through most of Southeast Asia. Its origin or causative agent remains unknown and no practical preventive measures are known. Fish dying of the disease are characterized by open lesions on the head and body, the fish finally succumbing to secondary fungal and bacterial infection. This disease is usually noticed in the cool season, and it is common for the disease to move from wild fish to cultured fish, especially *Puntius* spp., in areas where they coexist. Since the initial outbreaks, wild fish stocks have recovered and infected fish is rarely found, although Some have been seen in Svay Chrum District of Svay Rieng during the 1995 cool season. It is likely that this disease will occur sporadically and cause short-term, localized damage in the ricefield fisheries of Cambodia.

---

[2] Several techniques exist for this — e.g., watching the pond for half an hour and counting the number of times the air-breathing species break the surface, also feeling in the pond mud for the resting places of fish.

Ricefield culture fisheries[3]

In areas where naturally occurring fish are inadequate to meet the Cambodian farmers' need, fish are sometimes introduced to the ricefield for simultaneous culture. Under these conditions, the farmer is able to exert more control over the fish production system than in the wild capture system described earlier. Fish-deficit areas where aquaculture is appropriate are usually at a higher elevation than the main floodplain. Here, wild fish are not able to reach the fields or ponds in any numbers. Such areas are often not ideal for fish culture, having poorer soils and drying out early. The methodology used to develop zoning of Kompong Ro District, Svay Rieng, is a useful approach to determine where culture (as opposed to capture) fisheries should be promoted (Bunra and Gregory 1995).

From the AIT/Department of Fisheries field research project in Svay heng, it has been shown that fish can be cultured successfully in both wet- and dry-season rice. The major findings from this work follow.

Design of rice-fish culture systems

In many ways, the culture system copies the traditional system, except that seed is introduced by the farmer. Due to the uncertainty of the rains in the Svay Rieng region, rice-fish farmers usually create a refuge area in or close to the ricefield, where the fish can move to if the field starts to dry up. In Svay Rieng, this is usually a converted trap pond adjacent to the ricefield. (This pond can also be used for nursing fingerlings prior to the field being transplanted and before the fish are allowed access to the ricefield.) A deep water refuge is particularly important if the short dry season, which typically occurs from late July to early August in Svay Rieng, persists. Allowances must also be made for too much water during the monsoon and bunds surrounding the rice-fish system must be high enough to avoid even temporary inundation. Most farmers construct simple bamboo screens to regulate the water level. As with the wild fish system, at the start of the cool season, the fish start to return to the refuge pond as the fields dry out and the rice ripens. Here they can be held until harvest.

Fish species for rice-fish culture

A variety of indigenous and exotic fish are cultured in ricefields by farmers in Svay Rieng. Success has been achieved with stocking various ratios of several species (Table 8.2).

Table 8.2 Fish commonly cultured in Svay Rieng.

Common name	Species	Khmer name	Native	Feeding habit
Silver barb	*Puntius gonionotus*	trey chapin	Indigenous	Herbivorous
Snakeskin gourami	*Trichogaster pectoralis*	trey cantor	Indigenous	Herbivorous
Common carp	*Cyprinus carpio*	treycarp samunh	Exotic	Planktivorous
Nile tilapia	*Oreochromis niloticus*	trey tilapia	Exotic	Planktivorous
Tilapia	*O. mossambicus*	trey carophee	Exotic	Planktivorous
Silver carp	*Hypophthalmichthys molitrix*	trey carp sor	Exotic	Planktivorous

[3]This section is written based on 18 mo of field experience of promoting rice fish culture in Svay Rieng Province. The systems described may not be fully appropriate or even viable in other parts of the country.

Fingerlings of these species can be stocked individually or in a composite culture. Stocking ratios used by Svay Rieng farmers are in the range of 0.25-1 fish m^{-2} of total ricefield area. In Svay Rieng, farmers have identified two peak periods when they need fish—at transplanting and at harvesting (when they often have to feed additional labor). During these periods, they have neither the time to catch them nor the money to buy them. Farmers should therefore stock fish with this consideration in mind.

Management of fish culture in ricefields

Farmers in Svay Rieng usually purchase fish seed for rice fish culture in July or as soon as their refuge ponds have enough water. The fingerlings are usually reared in the small ponds until the rice has been transplanted for about 10 d. Rice varieties which tiller well in deeper water (20-30 cm) should be planted. The bund separating the fish from the field is then broken and the fish are given access to the ricefield. Farmers have observed a diurnal migration of fish taking place, with fish leaving the pond area in the evening and returning the following morning.

It is most important that large predatory fish species such as snakehead (*Channa striatus*) are not present in the pond or the field when fingerlings are first introduced as they will drastically reduce survival rates. However, farmers often have difficulty in removing such fish from the system. If farmers suspect that such predators are present, then larger fingerlings should be purchased or small fingerlings should be raised in an inverted mosquito net until they are large enough to escape predation. Predators entering the ricefield system after the cultured fish are established are less of a problem. Farmers in Svay Rieng have reported that rats will take fish from the ricefields at night.

Some additional ricefield management is necessary for successful rice-fish culture. Water levels must be regulated to ensure that the field does not dry up or flood. Usual rice fertilization regimes can be followed by the farmer. Although the fish present will control some of the softer weeds which grow in the field, some others will have to be removed by hand in the usual way. The fish will derive most of their growth from naturally occurring organisms in the field and these include benthic and epiphytic organisms such as worms, snails, insect larvae, and algae. Many farmers provide a variety of supplementary feeds including duckweed, termites, earthworms, and rice bran.

Fish culture in ricefields and integrated pest management

Until recently, few farmers applied pesticides on wet-season rice and, in those cases, the dilution effect of rain and outside water entering the system may be enough to prevent fish mortality from occurring. In irrigated rice where pesticides are often used as a prophylactic and where calendar spraying is common, culturing fish in ricefields really means that the farmer has to forgo the spraying of pesticides while fish are present in the field.

Research on the extent to which fish can control rice pests is inconclusive. As many of the pests conceal themselves within the rice plant, it is unlikely that fish can feed on them. It could be argued that beneficial insects such as spiders and wasps, being more mobile, will be more prone to predation by fish. Svay Rieng rice-fish farmers seem to accept some rice pest damage as the fish produced are usually more than enough to compensate for pest damage to the ricefields. In some instances, rice yields have been shown to increase in the presence of cultured fish possibly due to the better rice and water management techniques adopted by farmers.

Fish culture can therefore be used as a tool to espouse integrated pest management programs that discourage any use of pesticides in irrigated rice in Cambodia. With growing concerns about the golden snail becoming a rice pest in Cambodia, cultured fish may play a role in helping to control this animal. Common carp will eat large numbers of the juvenile snails.

Harvesting of cultured fish from ricefields

After 3 mo in the ricefield, the fish should have reached an edible size. They can then be caught from the ricefield or refuge by hooking or gill netting. Total harvests are usually done through pumping the refuge dry and catching the fish by hand. Fish culture often continues after the rice harvest, if enough water is available.

Cultured fish produced in wet-season ricefields may have to compete with a considerable number of wild fish in Cambodian markets in December-February. Prices for cultured fish at this time are often low (typically 1200-1500 riels kg^{-1}). (Figure 8.3 shows the yearly trend in Svay Rieng market prices and cultured fish are considered to be in the same group as the "small carps".) Due to water shortage, many farmers are forced to sell their fish earlier than they would want to and for less money. Other farmers process their fish as BaOrk, or eat them fresh.

Cultured fish from dry-season irrigated ricefields do not face such a competition. Usually produced in May-June, these fish fetch premium prices [typically 2500-2750 riels kg^{-1}) at a time when there are very few wild fish in the market place. This should encourage the development of irrigated rice-fish systems in some areas of Cambodia where water availability and soil quality are conducive to this activity.

Cultured rice-fish yields

From the limited data available, cultured fish production in wet-season and irrigated rice (with limited supplementary feeding) is usually in the range of 200-400 kg ha^{-1}. Due to seasonal price differentials, this has a respective value of 300,000-600,000 riels ha^{-1} from wet-season rice and 500,000-1,000,000 riels from irrigated rice. This compares favorably with rice production on the poorer soil areas of Svay Rieng where farmers expect rice yields of around 800 kg ha^{-1} (worth 400,000 riels at 500 riels kg^{-1}). In many cases, the value of fish produced will actually exceed the value of rice produced.

Cited references

Bunra S, Gregory R. 1995. Trap pond mapping as a survey tool for aquaculture development planning. Proceedings of a seminar on aquaculture in south and southeast Cambodia, 13-14 Dec 1995. Phnom Penh, Cambodia: Partnership for the Development of Cambodia. 82 p.

Spiller G. 1985. Rice cum fish culture: environmental aspects of rice and fish production in Asia. Report FAP/AP-15. Bangkok, Thailand: FAO Office for Asia and the Pacific. 48 p.

Constraints to rice Production and strategies for improvement

H. J. NESBITT

Cambodia achieved self-sufficiency in rice during the 1995-96 season after 25 yr of deficit. Maintaining this level of production and expanding the country's rice grain export base are dependent upon overcoming a number of development and environmental constraints. This chapter discusses these constraints and suggests possible strategies to overcome them.

Total rice production may be increased by expansion of cultivated area or through productivity increases by intensification of existing rice-based farming systems.

Production improvement through area expansion

Government statistics indicate that Cambodia's wet season rice-producing area decreased from 2,326,800 ha in 1967 to 1,868,900 ha in 1995. Over the same period, the area suitable for deepwater rice was reduced by 79% (315,400 ha) (Table 5.1). Several factors may contribute to the contraction and the failure to expand over recent years: lack of security discourages farmers from settling in large areas, land mines in many parts of the country prevent cultivation, and a labor shortage exists in the provinces. If these constraints to area expansion can be overcome, Cambodia has a good potential to become a major rice exporter.

Lack of security remains a problem in many areas that are suitable for production but remain uncultivated; much of the unused land is situated some distance away from roads and villages. Aside from being exposed to extortion activities of terrorists and bandits, the people in the villages are isolated because the land is far from schools and other facilities. Security problems in these areas will persist if insurgent and bandit activities are not reduced. This problem may, in part, be solved by improving the infrastructure. Construction of roads and schools and installation of irrigation or drainage facilities may speed up production.

The existence of mine fields also delays settlement on the land. Nesbitt et al (1995) calculated that in 1994, a total of 55,000 ha of mine fields were located on land encompassing ricefields, roads, and small plots of grazing land. By strategic location, many of the mines may not be situated in the paddies. Nevertheless, large areas still have to be cleared and this process is a slow one. At the rate the agencies are operating, it will take decades before all areas are cleared—the fields were not mapped accurately when laid and the mines were difficult to locate. However, farmers in these areas have lived with these mines for years and are able to cultivate around them. In a survey conducted by the International Center for the Red Cross (ICRC) in 1993 (as cited in Davies and Dunlop 1994), it was noted that most farmer victims were cutting firewood or collecting food in the forests at the time of injury. These activities can be curtailed with the incorporation of agroforesty projects into the farming systems.

Additional labor and draft power is also required to expand the cultivated area. Labor will be a constraint in Battambang, Banteay Meanchey and Siem Reap, the provinces with the greatest potential for area expansion.

Due to shortage in draft animals, deepwater rice areas—where timely operations are essential for a good crop—were not utilized. This shortage can be overcome with the introduction of suitable farm machinery. In 1994, approximately 240,000 ha of riceland were plowed by four-wheel tractors (see Chapter 7). Tractors are better than animal-drawn power in situations when timely operation is essential. In some areas, transplanting may also be replaced by direct seeding, reducing the dependence on farm labor even further. In addition, harvesters developed in Thailand can be adapted to conditions in Cambodia to relieve labor shortage at the end of the season.

Production increases through intensification

The current national rice yield, 1.5 t ha^{-1}, is one of the lowest in Asia. Increasing productivity from existing farms would improve the well-being of more than 80% of Cambodia's population. Benefits would extend to subsistence farmers through improved nutrition, and excess grain production would have considerable impact on the nation's economic viability.

The development of technology suitable for Cambodian conditions suffered severe setbacks during the war years, consequently lagging behind other countries in the region. Research facilities were destroyed, qualified personnel died or left the country, and the national agricultural research system (NARS) fell into disuse. The reestablishment of an effective NARS is necessary before many of the technological problems can be overcome and this is dependent on the establishment of a team of qualified and enthusiastic researchers.

In 1995, no Ph D-level trainees and very few masters degree holders were actively engaged in agronomic research. Training to this level in a range of subjects is required to return the Ministry of Agriculture, Forestry, and Fisheries and the Royal University of Agriculture (RUA) to a productive research status. In the near future, training to the post-graduate level is only possible through scholarships abroad. The establishment of nondegree, in-country training programs and sponsorship to training courses conducted in other countries by international and non-government organizations (NGOs) would also support the establishment of a strong NARS. For the in-country programs, facilities at the RUA and research centers require upgrading.

Improvement in technology is required in a number of disciplines ranging from management of infertile soils to development of appropriate grain storage facilities. Upgrading of facilities, technology transfer systems, and regulatory programs are part of the process.

Soil infertility is one of the most serious constraints to crop yield improvement in Cambodia. Laboratory analyses of the major soil types indicate deficiencies in N, P, K, S, and often Mg (CIRP 1989-93). Other macro - and micronutrient deficiencies are evident on these soils when fertilizers are applied. In addition, a number of problem soils exist exhibiting characteristics of iron toxicity, acidity, and high salt concentrations.

Natural infertility is inherent in Cambodian rice-growing plains as the ancient soils have been leached over thousands of years. Centuries of rice monoculture during which little or no fertilizers were applied contributed to their degradation. Estimates of inorganic fertilizer imports for 1995 indicate that low application rates remain current. At an importation level of

40,000 t yr^{-1}, consumption is extremely low, equaling an average national rate of approximately 20 kg of fertilizer (less than 10 kg ai) ha^{-1}.

An apparent solution to low yields is to subsidize fertilizer sales in an effort to increase consumption. This would lead to higher rates being applied on dry-season crops and, consequently, would improve productivity. However, nutrient balances in many of the impoverished rainfed soils are poorly understood and application of commercially available fertilizers are considered by farmers to be uneconomical. Replicated experiments often result in decreased yields with single nutrient applications and many farmers have been observed to sell donated products rather than apply them. A multilevel strategy is therefore required to resolve the problem. First, an innovative but simple system needs to be developed on which soils can be classified for agronomic purposes. An initial descriptive system presented in *"The soils used for rice production in Cambodia: a manual for their recognition and management"* (White et al 1997) is a marked improvement on the use of Croker's *"Soils of Cambodia"* (Croker 1962) and FAO's *"Soils of the Mekong Delta"* (1975) for developing fertilizer strategies. The system will be further developed as more data become available. Secondly, fertilizer recommendations need to be refined further for each soil type and possibly for micro ecosystems. Finally, a wider range of fertilizers must be imported or formulated within the country to cater to various soil types. Some soils may require only one nutrient, while others need three or four elements in proper balance to increase crop yields.

Traditionally, farmers apply farmyard manure and some cut-and-carry green manures such as *Chromalaena odorata* to maintain fertility levels in their fields. Farmyard manure supplies are, however, limited and nurseries receive most of the applied material. Incorporation of the introduced legumes including *Sesbania rostrata* have been shown to increase rice yields in the main ricefields. Soeun and Nesbitt (1993) demonstrated an average yield increase of 40% in on-farm trials using this technology. Farmers accepted the practice but a reliable source of legume seed must be developed. Cropping rotations incorporating cash crops are an additional way of improving soil fertility (Nesbitt and Phaloeun 1991a, b).

An expansion in the use of these low technology practices will lead to more sustainable farming systems. More research in the physical and social sciences is required to develop technologies appropriate for each ecosystem.

Poor water control is another major cause of poor crop yields in Cambodia. Heavy showers of rain falling at unpredictable intervals onto impermeable soils during the first 3 mo of the wet season cause intermittent periods of drought and temporary flooding in the rainfed areas. Temporary flooded conditions often preclude the cultivation of upland crops before rice and the mini-drought periods damage rice planted early in the season. Irreparable drought damage to seedling nurseries is also a serious problem.

Heavy rain in September and October, leading to deep water in the fields, encourages the cultivation of flood-tolerant varieties which do not possess potential for high yields. In years of low rainfall or an early end to the season, later duration varieties suffer from drought. In addition, when the river levels are abnormally low, flood recession rice areas are dramatically reduced. Reticulation systems in these areas are often inadequate to cater to all dry season farmers.

Strategies that may be employed to reduce the effects of the mini-drought periods include leveling of the fields to evenly distribute available water, raising of bund heights to retain water during wet periods, construction of small ponds beside nurseries for supplementary watering, drilling for underground water, and construction of irrigation systems where appropriate. The first three options are cheap but rarely employed. Existing techniques for well drilling need to be adapted and developed for Cambodian conditions by agricultural engineers and research agronomists before recommendations are made to firming communities. This would require expanded research and extension programs. The potential for increasing the area under full irrigation using pumps or gravity-fed systems is limited (ADB 1994) and requires thorough investigation before implementation. However, construction of canal systems in floodplains in the upper end of the Mekong Delta would assist drainage from and irrigation of recession rice areas.

Improved varieties need to be developed and/or introduced that more efficiently convert energy into grain when cultivated in discrete ecosystems. Cambodia currently possesses approximately 2,000 different varieties spread across various ecosystems (Makara 1996). This large number indicates the undeveloped nature of plant breeding in the country. Wide diversity has developed over centuries of on-farm selection and provides for variations in water depth, drought incidence, soil infertility, and other edaphic factors. These varieties do, however, tend to have low harvest indexes and are not responsive to improved conditions.

Modern plant breeding techniques can be employed to reduce wastage in plant biotype and increase rice yields in irrigated environments. For example, a yield increase of 25% over the controls was observed in on-farm trials when IR66, IR72, and IRKru were introduced to dry-season crops in 1991 (Chaudhary et al 1991). More recently, a 21% increase in grain yields was observed when pureline traditional varieties were released (see Chapter 5). Such plant breeding programs need to continue and must expand into seed multiplication programs.

Seed multiplication is an essential part of any successful plant breeding program. A system for multiplication and dispersal through regulated channels is almost nonexistent in Cambodia and needs to be established. This can be achieved by a government-controlled plant breeding program providing breeder and foundation seed for multiplication to a certified seed standard by farmers in their fields.

Insect pests, diseases, weeds, and animal damage are increasing in Cambodian rice crops, particularly in the dry season. Brown planthopper outbreaks and incidence of gall midge, leaf-folder, stem borer, sheath blight, and rats are regularly mentioned by farmers to be the primary cause of yield reductions. If effective pest control systems are not implemented, these problems shall escalate as the cropping systems are developed and intensified. Health and environmental issues are also at stake, with an increased use of dangerous and sometimes substandard chemicals (Nesbitt et al 1995).

Farmer awareness of optimal pesticide utilization and safe use needs to be improved. Implementation through a well-designed integrated pest management program of farmer field schools is required. A pilot program implemented by Canada's International Development Research Centre (IDRC), which began in 1992 and was continued by FAO in 1995, provided a good base for this development. The farmer field school system should be further developed and expanded, but this must be backed by good research to develop appropriate pest management strategies for Cambodia.

Labor-efficient weed control methods need to be developed for use by farmers in the more fertile soils, particularly in the direct-seeded areas of Battambang and Kandal.

Implementation of effective research and extension programs on rice-based farming systems requires a comprehensive reservoir of baseline information. Recent studies on soils

(White et al 1995), fertilizer use (Anonymous 1995), agricultural engineering (Rickman et al 1995), gender issues (Paris et al 1992), crop protection (see Chapter 6), social sciences (Lando and Mak 1994a,b,c), and the establishment of rice ecosystem maps have contributed considerably to knowledge in these disciplines. Such information need to be constantly refined and updated.

As mentioned in Chapter 4, rice-based farms are an integration of cropping with other farming activities. Cattle and buffalo are used for draft power while threshing and sale of pigs and cattle provide additional source of income. Much of the animal waste is used as fertilizers and as source of fuel for cooking. There is also potential for growing fish in the ricefields. Healthy animal and fish populations are therefore essential in productive rice farming; strong government programs to improve animal health must be put in place.

Firewood collection is a major time-consuming activity of most farmers (Helmers et al 1996). Forests close to settled areas are diminishing in size and some evidence indicates that flash floods and increased soil erosion have resulted from deforestation along the country's borders. Nesbitt et al (1996) also mention the plight of farmers being injured while collecting wood in forests lined with mines. Adoption of agroforesty techniques by farmers would reduce demand for off-farm resources and wood sales would provide a valuable source of income. Drainage is, however, a major problem in much of the rainfed area. Long-term research into the use of ditch and dike farming systems is required.

Technology transfer through an active extension program is essential before any of the above technologies can improve the efficiency of rice-based farming systems in Cambodia. As with the nation's research sector, considerable training and infrastructure support are required to develop an effective extension program.

Credit facilities, grain storage, and marketing of inputs and surplus grain have slowly improved over the years following the opening of the economy. Further improvements are envisaged toward the end of the century as the country's infrastructure improves with economic development.

Cited references

Anonymous. 1995. Cambodia: fertilizer marketing and distribution system. Agro-chem News (18)4:21-24.

Asian Development Bank. 1994. Notes on Cambodia's agricultural development options. Phase I (ADOR I). Aide Mernoire.

Chaudhary R C, Men S, Nesbitt, H J, Khush G S. 1991. Three new varieties of short-duration rice released in Cambodia. Int. Rice Res. Newsl. 16(4): 15-16.

[CIRP] Cambodia-IRRI-Rice Project. 1989-93. Annual research reports 1989-93. University Press, Phnom Penh, Cambodia.

Crocker C D. 1962. The general soil map of the Kingdom of Cambodia and the exploratory survey of soils of Cambodia. Royal Cambodian Government Soil Commission and United States Agency for International Development (joint publication). Phnom Penh, Cambodia.

Davies P. Dunlop N. 1994. War of the mines: Cambodia, land mines, and the impoverishment of a nation. London (UK): Pluto Press. 192 p.

[FAO] Food and Agriculture Organization. 1975. Soils of the Mekong Delta. National Geographic Institute, France.

Helmers K, Bleakely R, Sakkunthea S, Viseth, S K. 1996. Household economic and food security systems. A case study in Takeo. 100 p. (unpubl.)

Lando R P, Mak, S. 1994a. Rainfed lowland rice in Cambodia: a baseline survey. IRRI Res. Pap. Ser. 152. 20 p.

Lando R P, Mak S. 1994b. Deepwater rice in Cambodia: a baseline survey. IRRI Res. Pap. Ser. 153. 23 p.

Lando R P, Mak S. 1994c. Cambodian farmers' decision making in the choice of traditional rainfed lowland rice varieties. IRRI Res. Pap. Ser. 154. 17 p.

Makara O. 1996. Rice germplasm collection and conservation in Cambodia. Paper presented at the Fourth International Conference on Plant Genetic Resources for Food and Agriculture, 10-23 Jun 1336, Leipzig, Germany.

Nesbitt H J, Alvaran E, Chhay N. 1996. Rice production and land mines in Cambodia. (unpubl.)

Nesbitt H J, Hickey A, Phirun, I. 1996. Adulterated pesticides in Cambodia. Int. Rice Res. Notes 21 (1):51.

Nesbitt H J, Phaloeun C. 1991a. Rainfed lowland rice farming systems in Cambodia, status and research thrust. In: Proceedings of the Rainfed Lowland Rice Farming Systems Research Planning Meeting, Myanmar. Manila (Philippines): International Rice Research Institute. p 146-170

Nesbitt H J, Phaloeun C. 1991b. Physical, biological and socioeconomic characteristics and research activities of farming systems at the CARRDI, Cambodia. In: Proceedings of the Rainfed Lowland Rice Farming Systems Research Planning Meeting, Myanmar. Manila (Philippines): International Rice Research Institute. p 356-372.

Paris T, Mandac A.M, Chharom C, Puthea S 1992. An assessment of the economic contributions of women in rice farming in Cambodia. Paper presented at the International Workshop on Gender Concerns in Rice Farming, 19-25 Oct 1992, Chiang Mai, Thailand. 11 p.

Rickman J F, Pyseth M, Sothy O, Theary C, Nhem S. 1995. Farm mechanisation and crop production in Cambodia. Cambodia-IRRI-Australia Project Baseline Survey Report No 5. Phnom Penh: CIAP.20 p.

Soeun M, Nesbitt, H J. 1993. Rice-based farming systems research in Cambodia. Paper presented at the Asian Rice Farming Systems Network Meeting,30 Aug-3 Sep 1993, Suweon, Korea. 15 p.

White P F, Oberthur T, Domingo L V. 1995. Classifying Cambodian soils from a Cambodian perspective. Proceedings of an in-country workshop on the classification of soils used for rice production in Cambodia. Phnom Penh, Cambodia: Cambodia-IRRI-Australia Project. 92 p.

White PF, Oberthur T, Pheav Sovuthy. 1997. The soils used for rice production in Cambodia. A manual for their recognition and management. Manila (Philippines): International Rice Research Institute. 71 p.

9 789712 201004
ISBN 971-22-0100-7