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Survey of Rice Cropping Systems in Kampong Chhnang Province, Cambodia

Volker KLEINHENZ[1,*], Sophon CHEA[1], Ngin HUN[2]
([1]*Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, #17, Street 306, P.O. Box 81, Phnom Penh, Cambodia;* [2]*Provincial Department of Agriculture (PDA) Kampong Chhnang, Sangkat Ksam, Kampong Chhnang, Cambodia;* [*]*Present address: The Herbals Joint Stock Company, 8th Floor, BAC A Building, No. 9, Dao Duy Anh Street, Dong Da District, Hanoi, Vietnam*)

Abstract: Although Cambodia might have achieved self-sufficiency and an exported surplus in rice production, its rice-based farming systems are widely associated with low productivity, low farmer income and rural poverty. The study is based on a questionnaire village survey in 14 communes containing 97 villages of Kampong Chhnang Province from March to June, 2011. It analyzes the prevailing rice-based cropping systems and evaluates options for their improvement. Differences in cropping systems depend on the distance from the Tonle Sap water bodies. At distances greater than 10 km, transplanted wet-season rice cropping system with low productivity of about 1.6 t/hm^2 prevails. This deficiency can be primarily attributed to soils with high coarse sand fractions and low pH (< 4.0), use of 'late' cultivars, and exclusive use of self-propagated seeds. To improve this cropping system, commercial 'medium' cultivars help prevent crop failure by shortening the cultivation period by one month and complementation of wet-season rice with non-rice crops should be expanded. Areas adjacent (≤ 1 km) to the water bodies become inundated for up to seven months between July until January of each year. In this area, soils contain more fine sand, silt and clay, and their pH is higher (> 4.0). Farmers predominantly cultivate dry-season recession rice between January and April. Seventy-nine percent of the area is sown directly and harvested by combines. Adoption ratio of commercial rice seeds is 59% and yields average 3.2 t/hm^2. Introduction of the second dry-season rice between April and July may double annual yields in this rice cropping system. Besides upgrading other cultivation technologies, using seeds from commercial sources will improve yield and rice quality. Along with rice, farmers grow non-rice crops at different intensities ranging from single annual crops to intensive sequences at low yields.
Key words: rice cropping system; socioeconomic indicator; on-farm activity; rice production

While annual growth of the world's population between 2009 and 2015 is estimated 1.1% (World Bank, 2011), annual growth of the world's rice production is about 4.5% (FAO, 2011). The latter growth is due to the expansion in rice-cultivation area and the increase in productivity. There are, however, large differences in productivity among rice-growing nations and particularly in mainland Southeast Asia which is home to Thailand and Vietnam as the world's two prominent rice-exporting nations. While the world's paddy rice yield in 2009 averaged 4.3 t/hm^2 and that of Vietnam 5.2 t/hm^2, average yield in Cambodia reached only 2.8 t/hm^2 (FAO, 2011), which is one of the reason why export of milled rice (4 299 t in 2008) in Cambodia is only a fraction (0.05% and 0.09%) of that in Thailand and Vietnam.

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Corresponding author: Volker KLEINHENZ (v.kleinhenz@gmail.com)

Although the land endowment predestines Cambodia to exporting rice (Dawe, 2004), the predominant rice cropping system in Cambodia is the wet-season crop, which accounts for over 86% of the total rice area, and 90% of this area is rainfed (USDA, 2010). Some researchers have highlighted innovations in Cambodia for rainfed rice cultivation (Mak, 2001), however, others have pointed to the relationship between human poverty and such rainfed cropping systems (Fujisaka, 1991). In addition to the wet-season crops, Cambodia produces dry-season rice which includes irrigated dry-season rice and 'recession rice' (USDA, 2010). Recession rice is planted into receding floodwaters from Cambodia's major water bodies that comprise the Tonle Sap Lake, the Tonle Sap River and the Mekong River, which merge in Phnom Penh to become the Tonle Bassac River.

Low productivity is symptomatic for Cambodia's production of non-rice crops as well. For example, the

total production of vegetables in Cambodia in 2009 was only 21% of that in Thailand and 11% of that in Vietnam. Yields for these crops averaged 37% below yields in Thailand and 48% below those in Vietnam (FAO, 2011). The primary objective of the study is to provide an overview of existing rice cropping systems in selected communes in Kampong Chhnang Province, Cambodia. The study also classifies these cropping systems by identifying the main factors which determine their prevalence and evaluates solutions for improving these rice cropping systems within Kampong Chhnang Province, Cambodia.

MATERIALS AND METHODS

Study area

Cambodia comprises 24 provinces which are divided into 185 districts, 1 621 communes and 14 073 villages (NIS, 2008). Our study area encompasses 14 communes within three districts of Kampong Chhnang Province (Fig. 1). Their total population of 87 400 represents 19% of the province's and 0.6% of Cambodia's populace. Communes were selected on rural-development indicators including population density, poverty and human-development index (ADB, 2007). In comparison to Cambodia's national average, the region is characterized by high population density and above-average percentage of households living below the poverty line (NCDD, 2009).

Kampong Chhnang Province is located in the basin of the Tonle Sap Lake and the Tonle Sap River. The Tonle Sap Lake is the largest freshwater lake in Southeast Asia, covering an area of about 3 000 km^2 in the dry season (November to April) and about 16 000 km^2 in the wet season (May to October). The difference in the area between seasons is primarily due to the Tonle Sap River which drains the lake during the dry season and replenishes it when the waters of

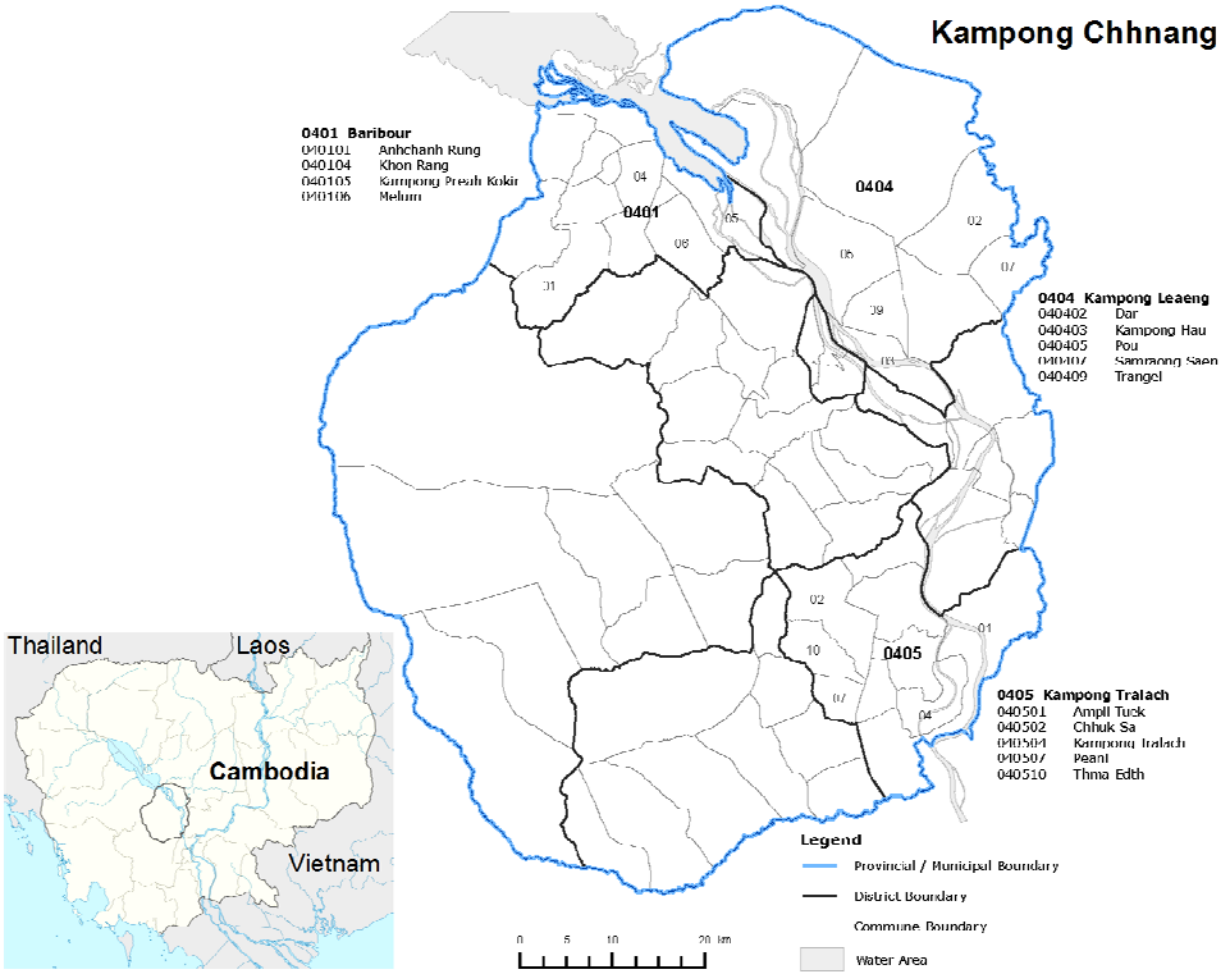

Fig. 1. Survey locations in Kampong Chhnang Province, Cambodia (adapted from MIC, 2010 and NordNordWest, 2009).

the Mekong River cause the reverse flow into the lake during the wet season. The seasonally inundated area up to 13 000 km^2 is usually referred to as 'floodplain'.

Table 1 presents an overview of our study area and the extent of seasonal flooding within the communes covered in this study. The average distance of each commune from the Tonle Sap River or the Tonle Sap Lake was calculated as the mean of the geographical distance of each commune's village to the closest water body. For this, GPS data was recorded using a mobile phone and 'My BB GPS' software version 1.6.0.

Fine and coarse sands are the prominent soil fraction across the study area (data not shown). In communes at distances greater than 10 km from the Tonle Sap soils with high coarse sand fractions and low pH (particle size: 1.6% clay, 2.6% silt, 28.7% fine sand, 67.1% coarse sand; EC: 0.01 dS/m; pH 3.8; exchangeable Al: 0.14 cmol/kg) prevail, whereas soils in areas adjacent (≤ 1 km) to the water bodies are higher in fine sand, silt and clay fractions with higher pH (2.7% clay, 5.8% silt, 37.1% fine sand, 54.3% coarse sand; EC: 0.02 dS/m; pH 4.3; exchangeable Al: 0.07 cmol/kg).

Surveys

The study was designed as a village survey in a total of 97 villages (2–14 villages per commune, data not shown). It encompassed interviewing key informants such as the Commune Councilor, the Commune Council Assistant, other Commune Council members, and a varying number of Village Chiefs and farmers between March to June, 2011.

The survey questionnaire contained two sections focused on rice cropping. Section one covered socio-economic indicators including household size and farm area, and section two focused on on-farm activities associated with rice production.

The commune-based interviews of key informants were conducted following the Delphi method (Linstone and Turoff, 1975) and divided into a maximum of three rounds. During the first round of interviews, the representatives of communes were asked to answer the questionnaire. These answers were reviewed and summarized by the interviewers for encouraging the informants to revise their earlier answers considering the answers of the other commune representatives. After such discussion, consent was usually reached in the second round.

Statistical analysis

Basic statistics including sums, means and standard deviations (SD), and analysis of variance (ANOVA) and multivariate analysis (cluster analysis) were calculated with SAS software version 9.2 (SAS Institute Inc., Cary). Differences among districts, clusters and groups of geographical distance were analyzed with one-factorial ANOVA and means separated with the Duncan test ($\alpha = 0.05$).

RESULTS

Basic characteristics of study area

The study area covers a total of 72 794 hm^2, 41% of which is for agricultural use on average (Table 1).

Table 1. Selected characteristics of surveyed communes in Kampong Chhnang Province, Cambodia.

Commune	District	Population	Area (hm^2)	Population density (km^{-2})	Ratio of agricultural area (%)	Farm size (hm^2)	Distance from Tonle Sap [a] (km)	Flooding [b] (month)	Ratio of flooding area (%)
Anhchanh Rung	Baribour	5 269	6 954	76	67	4.0	11.5	0	0
Khon Rang	Baribour	7 288	4 207	173	43	1.3	2.5	6	24
Kampong Preah Kokir	Baribour	1 983	3 000	66	41	2.9	0.0	5	100
Melum	Baribour	3 916	5 300	74	38	2.0	3.5	3	2
Dar	Kampong Laeng	6 759	8 500	80	36	2.2	1.0	5	13
Kampong Hau	Kampong Laeng	8 078	4 803	168	23	0.6	0.5	6	100
Pou	Kampong Laeng	5 249	9 350	56	25	1.5	2.5	0	0
Samraong Saen	Kampong Laeng	1 555	4 454	35	7	0.8	0.0	7	100
Trangel	Kampong Laeng	6 226	10 910	57	24	2.1	2.5	0	0
Ampil Tuek	Kampong Tralach	12 530	4 518	277	68	1.3	0.0	5	100
Chouk Sa	Kampong Tralach	9 083	3 753	242	62	1.1	10.5	0	0
Kampong Tralach	Kampong Tralach	6 519	1 599	408	63	0.8	0.0	3	63
Peani	Kampong Tralach	7 723	1 798	430	39	0.4	11.5	5	2
Thma Edth	Kampong Tralach	5 222	3 648	143	34	1.1	11.5	0	0
Mean		6 243	5 200	163	41	1.6			
Total		87 400	72 794						

[a] Average distance from Tonle Sap River or Tonle Sap Lake; [b] Period during the wet season when waters from the Tonle Sap Lake and Tonle Sap River floods the area between July and December.

While the ratio exceeds 20% in 13 communes, only 7% of the total area of Samraong Saen commune is used for agricultural purposes. This can be attributed to a flooding period of approximately seven months (July to January) during which the area is totally inundated. The total population of this area is 87 400. The population density ranges between 35 and 430 km^{-2} and averages 163 km^{-2}. With 18 193 households in total, the average household size is 4.7. Farm size averages 1.6 hm^2, ranging from 0.4 hm^2 in densely populated Peani commune to 4.0 in Anhchanh Rung commune.

Flooding by waters from Tonle Sap Lake and Tonle Sap River

Fig. 1 and Table 1 illustrate that only four of the 14 communes, i.e., Anhchanh Rung, Chouk Sa, Peani and Thma Edth, are more than 10 km away from the Tonle Sap Lake and/or the Tonle Sap River, and almost do not become flooded during the wet season. Other communes become inundated when the waters of the Mekong River flow into the Tonle Sap River and Lake during the season, except Pou and Trangel. Communes in close proximity to the water bodies including Kampong Preah Kokir, Melum, Kampong Hau, Dar, Samraong Saen, Ampil Tuek and Kampong Tralach experience 3–7 months of flooding during the wet-season months mostly from the end of July until the end of December (Samraong Saen: from the middle of July until the beginning of February). The wet-season flooding does not only affect these communes for a longer period of time but also affects a greater percentage of their area (Table 1).

Rice cropping systems

About 34% of the total area of the 14 communes is used for rice production, which corresponds to 83% of the arable land (Tables 1 and 2). Rice cropping systems can be divided into wet-season (about 69% of the total rice cultivation area) and dry-season production (31%). Except Kampong Tralach and Khon Rang communes where 30 hm^2 and 360 hm^2 are double-cropped, respectively, all the other areas in the study are single-cropped, i.e. one rice crop per year. Only in Pou and Trangel communes, some areas (13% and 5% of the total arable area, respectively) are currently not used for rice cultivation. Farmers singled out lack of labor as a primary reason.

In areas which are comparably distant from the Tonle Sap Lake or the Tonle Sap River (Anhchanh Rung, Chouk Sa, Peani and Thma Edth), farmers exclusively cultivate wet-season rice. While late cultivars mature within 5-6 months between June and November/December, medium cultivars require only 4–5 months between June and September/October. Farmers plant late rice cultivars for about 34% and medium cultivars for about 66% of the total area. This distribution does not only apply to the total area but also to the area on individual farms, i.e., a majority of farmers cultivate late and medium cultivars on different fields of their farms.

Although some farmers plant floating rice (Khon Rang, 380 hm^2; Dar, 140 hm^2; Pou, 220 hm^2; Trangel, 128 hm^2), the predominant cropping system in areas

Table 2. Characteristics of rice cultivation in surveyed communes in Kampong Chhnang Province, Cambodia. hm^2

Commune	Area	Wet season		Dry season		Directly sown [a]	Transplanted [b]
		Medium cultivar (June–October)	Late cultivar (June–November)	First crop (January–April)	Second crop (May–July)		
Anhchanh Rung	4 646	2 323	2 323	0	0	0	4 646
Khon Rang	1 700	1 020	680	360 [c]	0	0	1 700
Kampong Preah Kokir	700	0	0	700	0	0	700
Melum	2 000	540	1 260	200	0	1 880	120
Dar	2 480	1 990	0	490	0	240	2 240
Kampong Hau	992	0	0	992	0	592	400
Pou	1 690 [d]	860	0	610	0	0	1 690
Samraong Saen	118	0	0	118	0	0	118
Trangel	2 582 [d]	1 974	0	480	0	0	2 582
Ampil Tuek	2 937	0	0	2 937	0	2 937	0
Chouk Sa	2 015	1 411	604	0	0	0	2 015
Kampong Tralach	993	115	115	733	30	993	0
Peani	710	213	497	0	0	0	710
Thma Edth	1 225	858	367	0	0	0	1 225
Total	24 788	11 304	5 846	7 620	30	6 642	18 146

[a] Sown directly in the field and harvested with combine harvesters; [b] Transplanted: seedlings raised in a nursery, transplanted into the field and harvested by hand; [c] Transplanted into areas with a subsequent wet season rice crop; [d] Not all arable area currently used for cultivation.

where become flooded between July and December (Kampong Preah Kokir, Kampong Hau, Samraong Saen and Ampil Tuek) is a first dry-season rice crop. The seeds of this crop are sown in January immediately after the floodwater from the Tonle Sap recedes from the fields ('recession' rice) and harvested during April. This cropping system offers the opportunity of cultivating another (the second) crop from April/May until the onset of flooding in late July. Currently, however, only about 30 hm^2 in Kampong Tralach commune have been planted this crop and only since 2010. Although most of the production areas are only meters away from the waters of the Tonle Sap River/Lake, lack of irrigation equipment was singled out as the major hindrance to growing the second dry-season crop.

In communes geographically located between wet-season or dry-season rice areas (Khon Rang, Melum, Dar, Pou, Trangel and Kampong Tralach), farmers cultivate both crops. Depending on the natural water supply, these crops are grown on different fields within individual farms.

The cropping system determines the mode of cultivation. In contrast to wet-season crops which are traditionally pre-nursed, transplanted and harvested by hand, dry-season rice is usually directly sown and harvested by combines. While 60% of the dry-season cultivation area of 992 hm^2 in Kampong Hau commune is directly sown, the total dry-season cultivation area of 2 937 hm^2 in Ampil Tuek commune is cultivated using these practices. In Kampong Tralach, farmers have extended direct-sowing practices beyond the dry-season crop: not only 733 hm^2 of dry-season rice but also 115 hm^2 of wet-season rice are seeded directly and harvested by combine harvester (Table 2).

A feature across rice cropping systems is the use of self-propagated seeds. Exceptions from this practice include Ampil Tuek (2 937 hm^2) and Kampong Tralach (993 hm^2) where seeds for the dry-season crops are typically acquired from private seed companies. Seed rates exceed the recommended rates (directly sown in the dry season, 60–70 kg/hm^2; directly sown in the wet season, 80–120 kg/hm^2; transplanted in both seasons, 20–30 kg/hm^2) up to five-fold: The overall seed rate in the study area is 115 kg/hm^2, for wet-season transplanted rice 105 kg/hm^2 and for dry-season directly-sown rice 122 kg/hm^2. The highest seeding rates were recorded for Kampong Hau commune (195 kg/hm^2 for the first directly-sown dry-season rice crop) and Ampil Tuek commune (180 kg/hm^2 for the first and the second directly-sown dry-season crop).

Compared to the world's average paddy-rice yield of 4.3 t/hm^2 in 2009 (FAO, 2011), the average productivity of rice in the surveyed communes is significantly lower (2.5 t/hm^2, Table 3). Only yields in Kampong Tralach (3.5 t/hm^2), Ampil Tuek (4.0 t/hm^2), Kampong Preah Kokir (4.5 t/hm^2) and Kampong Hau (4.8 t/hm^2) approach or exceed the world's average. The factors influencing productivity include geographic location, season, cultivation mode and source of seeds. All communes with above-average rice productivity are located in close proximity to the Tonle Sap River where dry-season rice is the predominant cropping system, crops are almost exclusively sown directly, and commercial cultivars are cultivated in 59%

Table 3. Productivity of rice cultivation in surveyed communes in Kampong Chhnang Province, Cambodia. t/hm^2

Commune	Wet season			Dry season			Mean
	Medium cultivar (June–October)	Late cultivar (June–November)	Mean	First crop (January–April)	Second crop (May–July)	Mean	
Anhchanh Rung	0.8	1.0	0.9				0.9
Khon Rang	1.3	1.3	1.3	1.3		1.3	1.3
Kampong Preah Kokir				4.5		4.5	4.5
Melum	1.5	1.8	1.6	2.0		2.0	1.8
Dar	1.6		1.6	1.2		1.2	1.4
Kampong Hau				4.8		4.8	4.8
Pou	1.2		1.2	3.2		3.2	2.2
Samraong Saen				2.5		2.5	2.5
Trangel	2.0		2.0	3.5		3.5	2.8
Ampil Tuek				4.0		4.0	4.0
Chouk Sa	1.5	2.0	1.8				1.8
Kampong Tralach	2.5	2.5	2.5	4.5	4.5	4.5	3.5
Peani	1.8	2.5	2.2				2.2
Thma Edth	1.3	1.5	1.4				1.4
Mean	1.6	1.8	1.6	3.2	4.5	3.2	2.5

(Ampil Tuek and Kampong Tralach) of the total area. On average, dry-season rice yields (3.2 t/hm^2) exceed those of wet-season rice (1.6 t/hm^2) by 100% (Table 3). Low productivity of rice prevails in communes at distances from the Tonle Sap exceeding 10 km: rice yields in Anhchanh Rung, Thma Edth, Chouk Sa and Peani communes were only 0.9, 1.4, 1.8 and 2.3 t/hm^2, respectively. Farmers grow no dry-season crops in these communes and crops are exclusively transplanted.

While rice cultivation covers a total area of 24 788 hm^2 in the study area (Table 2), other crops occupy 2 699 hm^2 which corresponds to 11% of the paddy area, 9% of the agricultural area and 4% of the total area. This non-rice crop production is restricted to areas adjacent to the Tonle Sap Lake/River.

Categorization of cropping systems

The first approach of explaining differences in cropping systems between surveyed communes is categorizing communes into districts (data not shown). This clustering explains only that the average geographical area of communes between districts is statistically significantly different, i.e., communes in Kampong Laeng district are larger than those in Kampong Tralach district and that the reverse is true for population density and the ratio of agricultural area to the total area.

The second approach is a multivariate analysis based on the parameters distance to Tonle Sap Lake/River, the total area, total agricultural area, rice agricultural area, non-rice agricultural area, flooding period, flooding area, wet-season rice area, dry-season rice area, transplanted rice area, directly-sown rice area, rice yield and rice seed rate. This analysis results in three clusters (data not shown). Cluster 1 contains only Anhchanh Rung commune in Baribour district, cluster 2 comprises Dar, Pou and Trangel communes which all belong to Kampong Leaeng district, and cluster 3 is composed of the ten remaining communes across the districts. The results of this analysis are primarily based on highly significant ($P < 0.001$) differences in total area, agricultural area, wet-season rice area and transplanted rice area between clusters. Anhchanh Rung commune with a total area of 6 954 hm^2 (Table 1), of which 4 646 hm^2 (Table 2) are exclusively used for transplanted wet-season rice, is classified in a different cluster from all other communes. Cluster 2 comprises the three communes with large total area but more diversified rice production (wet-season and dry-season cultivation) whereas cluster 3 combines the communes of smaller individual area.

The third approach of differentiating cropping systems in the study is categorizing communes according to their distance from the Tonle Sap Lake or Tonle Sap River (Table 1). Among the 27 parameters subjected to analysis of variance, ten parameters revealed significant differences among the groups of communes based on the distance from the Tonle Sap Lake/River: (1) within 1 km (five communes including Kampong Preah Kokir, Kampong Hau, Samraong Saen, Ampil Tuek and Kampong Tralach); (2) between 1 and 10 km (five communes including Khon Rang, Melum, Dar, Pou and Trangel); and (3) beyond 10 km (four communes including Anhchanh Rung, Chouk Sa, Peani and Thma Edth) (Tables 1 and 4). While the average period and area during which waters of the Tonle Sap Lake and Tonle Sap River inundate parts of the surveyed communes decrease with distance from the water bodies, the share of dry-season rice area decreases and that of wet-season rice area increases. Since nearly all of the wet-season rice is transplanted, the area of transplanted rice increases and that of directly-sown rice decreases (not significantly) with distance from the lake/river. Due to this, there is a highly significant inverse relationship between the rates of dry-season rice area and wet-season rice area to total commune area. Since yields are higher for dry-season rice and the share of dry-season rice decreases with distance from the Tonle Sap Lake/River, average rice yields are more than double (3.6 t/hm^2) in communes close to the Tonle Sap Lake/River compared to communes at distances beyond 10 km from the Tonle Sap Lake/River (1.5 t/hm^2).

Table 5 summarizes the typical cropping systems prevailing in the study area of Kampong Chhnang Province in Cambodia throughout a year. While intensification of land use is restricted by seasonal flooding in close proximity (0–1 km) to the Tonle Sap Lake/River, cultivation of the second dry-season rice can be expanded beyond Kampong Tralach commune (System 1). The least extensive cropping system prevails at greater distance to the water bodies (> 10 km; System 1) where farmers typically cultivate only a single wet-season rice crop during a year.

DISCUSSION

Study area in the context of Cambodian and Southeast Asian agriculture

Approximately 83% of arable land in the study is used for rice cultivation. As such, the study area within Kampong Chhnang Province represents the structure

Table 4. Selected agricultural indicators by distance from Tonle Sap Lake/River.

Agricultural indicator	0–1 km	1–10 km	> 10 km	Mean	P [a]
Population (commune^{-1})	5 647	6 253	6 824	6 243	ns
Population density (km^{-2})	197	101	223	163	ns
Household size (household^{-1})	4.9	4.8	4.5	4.7	ns
Total area (hm^2/commune)	3 393	7 178	4 038	5 200	ns
Agricultural area (hm^2/commune)	1 404	2 164	2 223	1 963	ns
Rate of agricultural area to total area (%)	45	32	50	41	ns
Farm size (hm^2)	1.5	1.7	1.7	1.6	ns
Rice cultivation area (hm^2/commune)	1 180	1 907	2 149	1 768	ns
Non-rice cultivation area (hm^2/commune)	217	256	74	193	ns
Rate of non-rice area to agricultural area (%)	28	11	3	14	ns
Rate of non-rice area to rice area (%)	59 a	14 b	4 b	24	0.05
Flooding period (month)	5 a	3 ab	1 b	3	0.05
Flooding area (hm^2/commune)	3 243 a	1 162 b	8 c	1 427	0.01
Rate of flooding area to total area (%)	91 a	23 ab	<1 b	36	0.01
Rice area (hm^2/commune)	1 187	1 909	2 149	1 771	ns
Dry-season rice area (hm^2/commune)	1 130 a	522 ab	0 b	546	0.04
Wet-season rice area (hm^2/commune)	58 b	1 387 ab	2 149 a	1 225	0.02
Transplanted rice area (hm^2/commune)	205 b	1 455 ab	2 149 a	1 296	0.04
Directly-sown rice area (hm^2/commune)	983	452	0	474	ns
Rate of dry-season rice area to total area (%)	94 a	35 b	0 c	42	0.00
Rate of wet-season rice area to total area (%)	6 c	65 b	100 a	58	0.00
Dry-season rice seed rate (kg/hm^2)	116	127		122	ns
Wet-season rice seed rate (kg/hm^2)	100	110	101	105	ns
Average rice seed rate (kg/hm^2)	116	123	101	115	ns
Dry-season rice yield (t/hm^2)	3.9	2.7		3.2	ns
Wet-season rice yield (t/hm^2)	2.5	1.6	1.5	1.6	ns
Average rice yield (t/hm^2)	3.6 a	2.4 ab	1.5 b	2.5	0.01

[a] Significance group effect (analysis of variance).
Data followed by different lowercase letters differ significantly-DUNCAN (0.05), within row comparison.

Table 5. Typical cropping systems (land use) by distance from Tonle Sap Lake/River.

Month	0–1 km			1–10 km			> 10 km	
	System 1	System 2	System 3	System 1	System 2	System 3	System 1	System 2 [a]
January	DSR1	VEG1 [c]	Flooded	Flooded	DSR1	VEG1		VEG1
February	DSR1	VEG1	VEG1	VEG1	DSR1	VEG1		VEG1
March	DSR1	VEG1	VEG1	VEG1	DSR1	VEG1		
April	DSR1	VEG1	VEG1	VEG1-VEG2	DSR1-VEG1	VEG1		VEG2
May	DSR2 [b]	VEG1	VEG2	VEG1-VEG2	VEG1-VEG2	VEG1		VEG2
June	DSR2	VEG1	VEG2	VEG2	VEG2	WSR	WSR	VEG2
July	DSR2	VEG1	VEG2	VEG2	VEG2-VEG3	WSR	WSR	VEG2
August		Flooded		Flooded	VEG3	WSR	WSR	
September		Flooded		Flooded	VEG3	WSR	WSR	VEG3
October		Flooded		Flooded	Flooded	WSR	WSR	VEG3
November		Flooded		Flooded	Flooded	WSR [c]	WSR [c]	VEG3
December		Flooded		Flooded	Flooded			VEG1

[a] Chouk Sa commune. [b] Kampong Tralach commune; [c] Late cultivar.
DSR, Dry season rice crop (directly sown); VEG, Vegetable crop; WSR, Wet season rice crop (transplanted).

of rice production in Cambodia and 'monsoon' mainland Southeast Asia (Masumoto, 2005). While the household size of 4.7 (Table 4) equals the average of Cambodia (NIS, 2008), farm size (1.6 hm^2) is 33% greater than the national average of 1.2 hm^2 per household (USDA, 2010). Mean population density (163 km^{-2}) in the study area is, however, approximately double that of Kampong Chhnang Province (85 km^{-2}) and Cambodia (75 km^{-2}) (NIS, 2008). The highest population density prevails in Kampong Tralach (408 km^{-2}) and Peani (430 km^{-2}). In comparison, population density of Southeast Asia is 126 km^{-2} including the Philippines (288 km^{-2}), Vietnam (254 km^{-2}), Thailand (127 km^{-2}) and Laos (26 km^{-2}). The study area can, thus, be characterized as a region with high population density but relatively low population pressure on farmland (Chhetry, 2001).

Cropping systems in Southeast Asia are defined by

distinct wet and dry seasons (Huke and Huke, 1997; Lau and Yang, 1997). In contrast to Thailand (25%) and particularly Vietnam (53%), however, only 16% of rice area is irrigated in Cambodia (Jamora, 2010). Largely because of this, rainfed wet-season rice dominates its cropping systems, which accounts for over 90% of its total wet-season crop area (USDA, 2010). Three of the 14 communes included in the study (Anhchanh Rung, Peani and Thma Edth) represent this traditional cropping system with a single wet-season rice crop cultivated without supplemental irrigation. While these communes are at least 10 km away from the waters of the Tonle Sap Lake and Tonle Sap River, the predominant rice cropping system changes with decreasing distance from the water bodies. In communes located at 1–10 km distance to the Tonle Sap Lake/River (Khon Rang, Melum, Dar, Pou, Trangel and Kampong Tralach), farmers grow both wet-season and dry-season rice which makes them less vulnerable to shocks like crop failure in either season. Communes in direct proximity to the river (0–1 km distance to the Tonle Sap Lake/River) have no option to cultivate a wet-season crop since they get inundated by the waters of the Tonle Sap during this season. Farmers in these communes (Kampong Preah Kokir, Kampong Hau, Samraong Saen and Ampil Tuek), hence, exclusively grow dry-season crops. Since the natural environments close to the Tonle Sap Lake/River provide a source for irrigation during the dry season, farmers in these communes compliment rice crops with extensive to very intensive cultivation of non-rice crops. While 100% of communes at a distance of up to 1 km from the Tonle Sap cultivate non-rice crops, this percentage drops to 80% for communes at distances between 1–10 km and 25% for communes at distances greater than 10 km from the Tonle Sap Lake/River.

Wet-season rice cropping systems

Although some farmers plant floating rice in communes close to the Tonle Sap (Khon Rang, 380 hm^2; Dar, 140 hm^2; Pou, 220 hm^2; Trangel, 128 hm^2) during the wet season, the rice planting area is rapidly declining, e.g., from 900 to 140 hm^2 in Dar commune during the past three years. Reasons for this decline include the long cultivation period (8 months between June and January) and low yield (about 1.2 t/hm^2).

In areas at greater distance to the Tonle Sap Lake/River, particularly in Anhchanh Rung, Chouk Sa, Peani and Thma Edth communes, the traditional crop is the late wet-season crop with a cultivation period of 5–6 months. This crop is increasingly being replaced by medium crops with a cultivation period of 4–5 months. Farmers have already cultivated the medium crops on 66% of the total wet-season rice production area of 17 150 hm^2 and usually plant both types on different fields of their farms to alleviate the risk of crop failure. The advantage of medium cultivars is that they are less affected by drought during grain filling and ripening (Fukai, 2006). In Anhchanh Rung and Peani communes, farmers estimate the risk of losing the whole (late) crop due to drought during the end of the cultivation period at 40%. While this risk is circumvented by medium rice cultivars, the disadvantage of the late cultivars is that their harvest during the end of the wet season may be hindered by submerged field conditions and/or localized flash floods during that time. The high rate of adoption of medium rice cultivars, however, illustrates the success of their promotion by the local authorities including the Provincial Department of Agriculture.

Farmers exclusively propagate seeds for their wet-season rice by themselves. In Trangel commune, farmers grow a wet-season cultivar introduced in 1979. During the past 32 years, they consequently used part (7%) of their annual harvest for sowing the crop in the subsequent season. It can be presumed that the poor quality of the seeds particularly in terms of genetic consistency contributes to the low yield of 1.6 t/hm^2, which is 63% below the world's average paddy rice yield of 4.3 t/hm^2 (FAO, 2011). Poor germination might be one of the reasons for high seed rate of 105 kg/hm^2 which highly exceeds the recommended rates for transplanted rice (20–30 kg/hm^2). Local authorities have just initiated a program of distributing seeds of commercial cultivars under the precondition that farmers do not propagate them for longer than three seasons.

The most significant contributor to low yields, however, appears to be prevalence of sandy acid soils at the southern end of the Tonle Sap Lake (Hin, 2010). Low water-holding capacity and low fertility of these soils are singled out as the predominant factors negatively affecting yields in this zone. Although the introduction of improved (medium) rice cultivars has lowered the risk of crop failure in some locations, they have not significantly improved the yield levels. Experiences with inorganic fertilizers including urea and diammonium phosphate have apparently not appreciably improved the productivity either. This might presumably

be related to inappropriate scheduling of applications and/or leaching. Development of permanent irrigation, i.e., switching from rainfed to irrigated cultivation may have a significant impact on improving productivity in this area albeit with low water-use efficiency. Another reason for limited use of inorganic fertilizers is their cost (about 0.60 US$/kg for urea and 0.80 US$/kg for diammonium phosphate) since they are exclusively imported (legally or illegally) from Thailand or Vietnam. It can only be speculated if additions of organic sources of fertilizers including compost might be able to improve the water-use efficiency and the productivity by increasing the water-holding capacity of soils (Leu et al, 2010). Such practices are, however, currently practiced only on a very limited scale.

Wet-season rice is entirely pre-nursed, transplanted and harvested by hand, with one exception in Kampong Tralach commune. In line with 763 hm^2 of dry-season area, farmers sow an area of 230 hm^2 directly with wet-season rice and use combines for their harvest. Although this figure is currently marginal (1.3%) for the total wet-season rice area of 17 150 hm^2 in the study, it may be expected that the share of directly sown rice in the wet-season cropping systems will increase in the future (De Datta, 1986).

Dry-season rice cropping systems

Due to seasonal flooding, communes less than 1 km away from the Tonle Sap Lake/River (particularly Kampong Preah Kokir, Kampong Hau, Samraong Saen, Ampil Tuek and Kampong Tralach) have no agricultural area available to cultivate a rainy-season crop. The total area affected by seasonal flooding in these communes is 20 039 hm^2 (92% of their total agricultural area) and the number of affected people 36 653. Since this land becomes completely inundated for 3–7 months of each year (between the end of July and December), people can farm their land for only 5–9 months of each year and resort to fishing activities during the flooding period. Despite this apparent disadvantage, this area is comparably highly populated with up to 408 people/km^2. People in the area have adopted their livelihoods to the prevailing natural conditions by modifying their cropping systems so that these do not resemble the typical rice-cultivation system in the greater part of Cambodia.

Dry-season flood-recession rice is the major land use in the area which Fox and Ledgerwood (1999) called an extremely productive and sustainable 'ancient land-use system'. The share of dry-season rice cropping systems in this area is 95%. The first dry-season rice is cultivated from the beginning of January when the floodwaters of the Tonle Sap Lake/River recede from the fields. During the 3-month cultivation period until April, this crop may be additionally irrigated. Since natural soil water reserves only lasts for a few months, farmers in this agro-ecological zone require short-season rice cultivars. Seeds for dry-season rice are not as readily available as for the wet-season rice, consequently, a greater percentage of those seeds (59%) are acquired from commercial sources.

Rice yields for the first dry-season average 3.2 t/hm^2, which doubles the yield level of the wet-season rice (1.6 t/hm^2). Yields in Kampong Preah Kokir (4.5 t/hm^2) and in Kampong Hau (4.8 t/hm^2) even exceed the world's average paddy rice yield of 4.3 t/hm^2 (FAO, 2011). Availability of water and soils with greater water-holding capacity ease soil water management in this area while fertile silt which deposits during the annual floods (Fox and Ledgerwood, 1999) contributes to soil fertility. Both conditions improve the rice productivity in this area.

A distinguishing feature of the dry-season cropping systems compared to the wet-season cropping systems is the use of direct-sowing and combine-harvesting practices. Commune members singled out two primary reasons for this very recent development. The first reason is limited availability of labor for nursing, transplanting and harvesting rice crops by hand, and the second reason is the unpredictability of the exact time when the receding floodwater allow the establishment of the crop. The first reason appears questionable since household size in the communes close to the Tonle Sap Lake/River is not significantly different from that of communes more distant from the waterway. The second argument may be more significant: if the floodwater recedes too early, seedlings are too young to be transplanted. In contrast, if the floodwaters recede just one or two weeks after the anticipated date, rice seedlings in the nursery may become over-mature since they should be transplanted within a short period of three weeks after sowing. The other disadvantage of nursing seedlings in this area is that seedlings need to be raised in elevated nurseries or fields which are not submerged beyond a few centimeters during that time. To avoid the risk of raising seedlings and to save cultivation time in the fields, some farmers sow germinated seeds, a cultural practice between sowing seeds and transplanting seedlings.

Both commune council and farmers have singled out cultivation of the second dry-season rice as the

primary development goal in the area. This crop can be cultivated after the harvest of the first dry-season crop in April until the onset of flooding during late July. Currently, the planting area of the second dry-season rice is only 30 hm^2 in Kampong Tralach commune and only since 2010. Communes with the greatest potential of introducing and expanding cultivation of the second dry-season crop include Kampong Preah Kokir (700 hm^2), Kampong Hau (992 hm^2), Samraong Saen (118 hm^2), Ampil Tuek (2 937 hm^2) and Kampong Tralach (703 hm^2). Communes with less potential comprise Khon Rang (360 hm^2), Melum (200 hm^2), Pou (610 hm^2) and Trangel (480 hm^2). If only 50% (3 500 hm^2) of these 5 450–7 100 hm^2 are used for rice cultivation with an average yield of 3.2 t/hm^2, it will result in an extra rice production of 11 200 t. This extra quantity almost doubles the total rice production (23 914 t) within the communes Kampong Preah Kokir, Kampong Hau, Samraong Saen, Ampil Tuek and Kampong Tralach, and increases the total rice production within the study area (53 219 t) by 21%. At a producer price of 199 US$/t in Cambodia in 2008 (FAO, 2011), this production has a total value of US$2.2 million.

The most significant prerequisite for cultivating the second dry-season rice crop is irrigation. Farmers indicate that appropriate irrigation pumps cost around US$250 and require about 120 L/hm^2 of fuel. While this is a significant investment for many or most farmers in the study area, farmers spent 75 US$/$hm^2$ for harvesting the first directly-sown crop by combine. If the yield of 3.2 t/hm^2 is completely sold at a producer price of 199 US$/t, a farmer will receive a return of 637 US$/$hm^2$ or US$828 for the average farm size of 1.3 hm^2 in these communes. In other words, farmers have to sell the production of about 0.4 hm^2 to offset the costs of a newly-acquired pump and about 0.7 hm^2 to offset those for a new pump and fuel (1.5 US$/L). If only fuel costs are taken into consideration, these costs can be offset by selling the harvest of only 0.3 hm^2, i.e., 1 t of rice. The fuel requirements can be reduced by saving irrigation through raising rice seedlings and transplanting the second dry-season crop. This technique does not incur the risks prevailing for the first dry-season crops, but farmers might be reluctant or unable to switch back to this labor-intensive form of rice cultivation.

Much similar to the wet-season cropping systems, seed rates for directly-sown dry-season rice exceed twice of the recommended rates: while 60–70 kg/hm^2 are recommended, farmers on average use 122 kg/hm^2, with 195 kg/hm^2 in Kampong Hau and 180 kg/hm^2 in Ampil Tuek communes. Since not all seeds are self-propagated as in the wet-season rice cropping systems, these practices waste farmers' agricultural, nutritional as well as financial resources. To improve these as well as other cultivation practices, the commune council members in this area call for better training of farmers preferably by way of demonstration fields.

CONCLUSIONS

The high percentage of 83% of the arable land in the study used for cultivation of rice predisposes the area to producing rice in excess of the requirements of its own population. It can potentially contribute to Cambodia redeeming its traditional role as a rice-exporting nation. The study highlights that there is no single solution for improving rice production not even within the geographically localized region covered by this survey. While two approaches of clustering cropping systems failed, the approach of categorizing them by the distance from the Tonle Sap Lake/River was successful and pointed towards routes for improving productivity. Establishing irrigation infrastructure is a prerequisite for expanding production of rice and non-rice crops. In areas distant to the Tonle Sap Lake/ River, introducing high-yielding medium maturing cultivars in the wet-season rice cropping system has already proven its potential for leveraging the risk of crop failure caused by occasional drought during the grain ripening stage at the beginning of the dry season in November. In the prevailing dry-season cropping system of communes adjacent to the Tonle Sap Lake/River, introduction of a second dry-season rice crop between April and July can possibly double annual yields and contribute to Cambodia's efforts to expand production of export-quality rice crops. Complementation of rice with non-rice crops should be promoted in these cropping systems, and the low yields call for improved cultivation technologies for these crops as well.

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