Soil Erosion Problems In Northeast Thailand: A Case Study from the View of Agricultural Development in a Rural Community Near Khon Kaen

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Abstract

We uncovered relations among soil erosion problems, farming practices and agricultural landscape in the study site. The introduction of cash crops in the upland starting in the 1970s caused a drastic change to the agricultural landscape, i.e., the former landscape, which was composed of forest-covered uplands and lowlands occupied by rain-fed paddy fields for cultivation of subsistence rice, has completely changed into the new landscape formed by the replacement of forests with crop fields in the upland. Agricultural development from the introduction of cash crops resulted in the birth of a new village from a mother village in the study site. Such agricultural development also caused soil erosion problems in rain-fed paddy fields of the lowland as well as crop fields of the upland. Soil erosion of crop fields, which were converted from forests to sustain the population growth of the rural community, was caused by the modification of site hydrology by decreasing the infiltration capacity, coupled with a strong intensity of rainfall in the rainy season and sandy soil. On the other hand soil erosion of rain-fed paddy fields resulted from culverts in the road that crossed the valley of rolling hilly land. This unique erosion could be caused by the imbalance between the road improvement due to the development of rural community and farming systems of rain-fed paddy fields that remained unchanged in spite of the development of rural community. In conclusion, agricultural development of the study site caused not only the typical soil erosion in crop fields of the upland, but also the unique soil erosion in rain-fed paddy fields of the low land. Both types of soil erosion depend on underlying factors such as agricultural development, rural community transformation, and population growth as well as by direct factors such as rainfall intensity, topographical features, farming systems and road culverts.

Keywords: soil erosion, agricultural development, crop fields, rain-fed fields, rolling hilly land

Introduction

The agriculture of Thailand has shifted from subsistence farming to a cash crop culture since the 1960s to develop the socio-economy of the country. This shift has resulted in conversion of forests to cultivated lands. As a result, rapid deforestation occurred and then soil erosion in crop fields has become a serious problem of resource degradation. Thus, the soil erosion problem of crop fields has generally been recognized since the old days. In Northeast Thailand, once forests typically covered the upland and rain-fed paddy fields stretching into the lowlands where topography is characterized by rolling hilly land that is composed of the uplands (hills) and the lowlands (valleys). A wave of agricultural development reached also this region at the end of the 1960s (Japan Agricultural Development and Extension Association, 1996). Since then, the agricultural landscape has rapidly changed. Now, expanses of crop fields have generally replaced the forests in the uplands, while stretches of rain-fed paddy fields still occupy the lowlands. Such agricultural development of this region also has resulted in typical soil erosion in crop fields of the uplands the same as other regions. Notably soil erosion in rain-fed paddy fields, which was not reported before, has been found by our field survey. This unique soil erosion seems to be closely related to topographical features and socio-economic conditions, and seems to characterize soil erosion problems in Northeast Thailand.

This paper aims to reveal relations between natural features and socio-economic conditions determining the distinctive feature of soil erosion problems in Northeast Thailand through clarifying the actual condition of agricultural development, rural community transformation, farming practices, and agricultural landscape changes constrained by topographical features, and analyzing the interaction among the above factors. For this purpose, we conducted a case study in the Khon Khwang and Non Jalern villages of Maha Sarakham Province.

pp. 675–686

Table 1. Data list for regression equation on basin area and specific suspended sediment production

Basin	Region	Total station	Basin area (km^2)	Regression equation	R^2
Japan		66	16-782	$S/A=882A^{-0057}$	0.401
Salawin	N	31	24-8,360	$S/A=14.81A^{0.296}$	0.887
Kok	N	22	51-10,300	$S/A=32.60A^{0.142}$	0.958
Ping	N	61	2-42,704	$S/A=12.96A^{0..219}$	0.943
Nan	N	15	90-25,294	$S/A=17.57A^{0.239}$	0.904
MeKong	N, NE	44	12-419,000	$S/A=20.20A^{0.198}$	0.937
Chi	NE	31	158-47,391	$S/A=56.24A^{-0.011}$	0.817
Mun	NE	35	61-117,000	$S/A=79.72A^{-0.177}$	0.693
Pasak	C	8	67-14,522	$S/A=2132A^{-0.425}$	0.646
Prachin Buri	E	11	45-7,502	$S/A=60.83A^{-0.026}$	0.903
Bang Pa Kong	E	5	128-8,360	$S/A=4955A^{-0.784}$	0.424
East Coast-Gulf	E	8	45-671	$S/A=707.2A^{-0.322}$	0.359
Mae Klong	W	22	67-26,441	$S/A=21.61A^{0.223}$	0.901
Phetchaburi	W	4	264-2,207	$S/A=2.203A^{0.389}$	0.856
Prachuapkhiri-khan Coast	W	5	93-2,370	$S/A=7391A^{-0.785}$	0.095
Peninsula East Coast	S	24	11-1,638	$S/A=30.97A^{0.146}$	0.677
Tapi	S	14	36-4,415	$S/A=173.6A^{-0.086}$	0.806
Thale Sap Song Khla	S	8	14-1,562	$S/A=181.6A^{-0.240}$	0.922
Peninsula West Coast	S	18	16-1,801	$S/A=57.37A^{0.081}$	0.745

S/A : specif. susp. sedi. Yield (ton/km^2/year) R^2 : coefficient of determination

S : ann. susp. sedi. Yield (ton/year), A: basin area (km^2)

C: Central region, E: East region, N: North region, NE: Northeast region, S: South region, W: West region

General status of soil erosion and agricultural development in Thailand

Based on the data of suspended sediment observed during the past three decades by three government agencies, i.e., Royal Irrigation Department, Electricity Generating Authority of Thailand and Department of Energy Development and Promotion (RID, 1998), specific suspended sediment production defined as the annual suspended production per unit area, can be summarized in Table 1 and Fig.1. Also, they show specific sediment production of Japan that is defined as the annual sediment production per unit area, estimated by using the reservoir sedimentation data (Kishi, 1987) to compare with that of Thailand. We can see some interesting tendencies in soil erosion of Thailand. First, the suspended sediment production rate of Thailand was considerably lower than that of Japan, which may be due to the difference in sediment production types between Thailand and Japan, i.e., sediment production of Thailand could result mainly from soil erosion, whereas that of Japan could result mainly from mass wasting such as landslides and debris flows. Second, in many basins of Thailand, particularly basins in the north region, the exponent of the equation relating specific suspended sediment production and basin area has positive values in spite of the fact that worldwide it has negative values in general (Walling, 1983). Positive values of the exponent may suggest that the sediment source is in the lower part rather than in the upper part of basins since negative values have been generally explained in terms of the decreasing slope and channel gradients and increasing opportunities for deposition associated with increasing basin size (Walling, 1983). If so, agricultural activities, particularly field crop cultivation in the lower part of basins could contribute to sediment production in Thailand.

Agricultural development of Thailand has resulted in rapid deforestation during the past four decades. According to statistics (Royal Forestry Department, 2000; National Statistical Office, 2003; Hasegawa, 1992; Tasaka, 1994), the area of forests for the whole of Thailand decreased from 29.1 million hectares (56.7 percent of the total land) in 1961 to 13 million hectares (25 percent) in 1998 (Fig.2). According to the FAO Statistical Database (2005), the area of crop fields increased from 1 million hectares (2 percent) in 1962 to 4.6 million hectares (9 percent) in 1999 (Fig.3: main cash crops of all crops), and the area of paddy fields also increased from 6.7 million hectares (13 percent) in 1962 to 10.5 million hectares (21 percent). The most deforested region is Northeast Thailand. The replacement with field crops caused a rapid reduction in forest area from

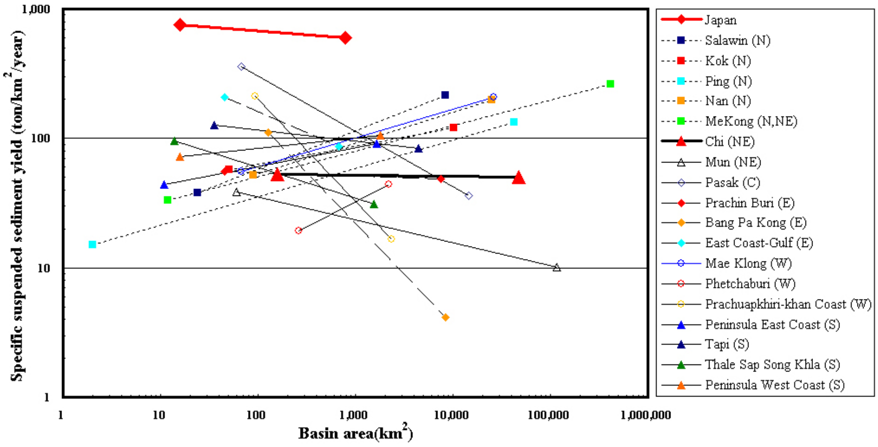

Fig. 1. Relations between basin area and specific suspended sediment production for main basins. N: Northern region, NE: Northeastern region, C: Central region, E: Eastern region, W: Western region, S: South region

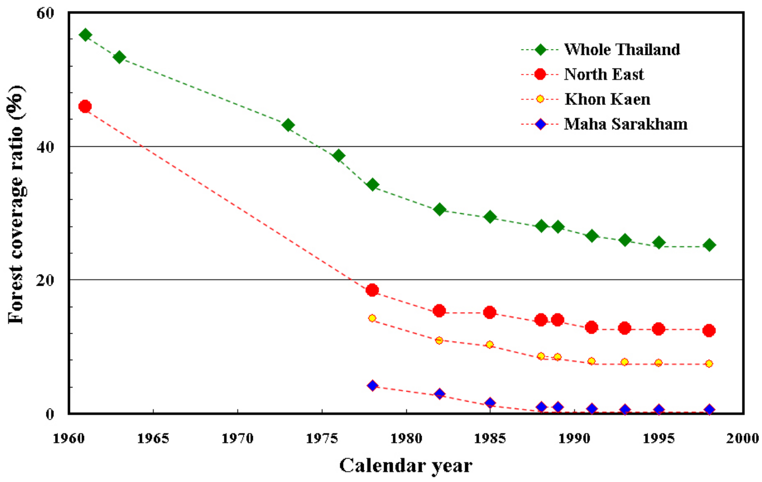

Fig. 2. Changes in forest coverage ratio of the whole Thailand, Northeast region, Khon Kaen and Maha Sarakham Provinces

7.1 million hectares (42 percent for the area of this region) in 1962 to 2.1miilion hectares (12 percent) in 1999. Thus, the area of crop fields dramatically increased 0.2 million hectares (1.2 percent) in 1962 to 1.9 million hectares (11 percent). As for paddy fields, the area has remained a stable 6–7 million hectares during the past four decades though the area for the whole country has increased by 1.6 times. Now the area of paddy field in this region accounts for 57 percent of the whole country. Thus this region is the most active area in rice production though the irrigated area is only 14 percent. The yield largely fluctuates with the weather because most paddy fields are rain-fed.

Study site in Northeast Thailand

The Khon Khwang and Non Jalern villages (Lat.: N16°14.6′, Lon.: E102°54.9′) near Khon Kaen city were selected as the study site that belongs to the Kosum Phisai district of Maha Sarakham Province (Fig.4) to conduct a case study. The geology of the study site consists of Mesozoic sedimentary rocks overlaid by Quaternary deposits composed of sandy loam in the surface layer (Imaizumi it et al., 2002). The topography is classified as rolling hills, which undulate with a relative height of about 10 m in the study site and neighboring area. Elevations range from 170 m to 200 m above sea level. The region has a tropical monsoon climate characterized by a rainy season from May to October and a dry season from November to April. The mean annual rainfall in Kosum Phisai near the study site is 1150 mm: 1005 mm (87%) falls during the rainy season,

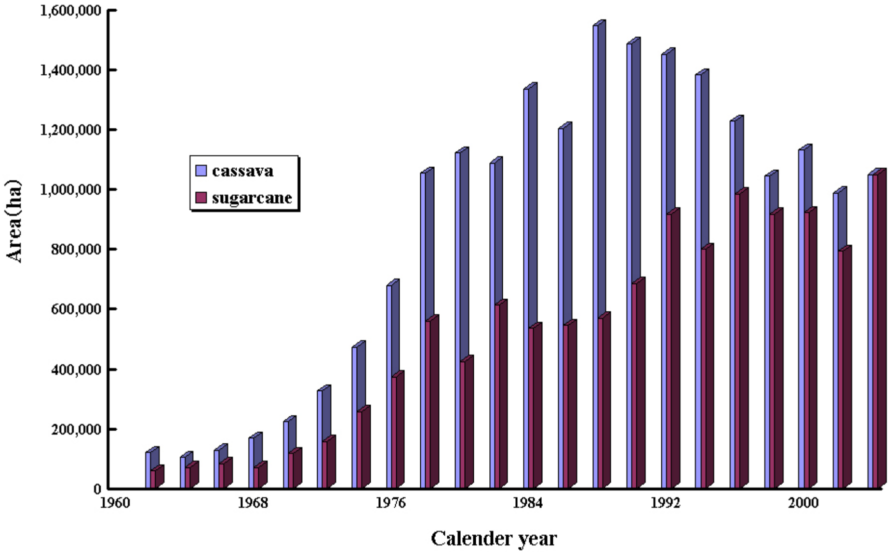

Fig. 3. Changes in the cultivation area of cassava and sugarcane in the whole of Thailand (FAO Statistical Databases (2005), http://faostat.fao.org/faostat/)

Fig. 4. Changes in the cultivation area of cassava and sugarcane in the whole of Thailand (Map showing study site (Khon Khwang and Non Jalern villages near Khon Kaen City)

and 145 mm (13%) falls during the dry season. The present land use in the study site is as follows: lowland, which is formed by the first order stream of the Chi River, is mainly used for paddy fields, whereas upland, which was covered by forests in the early 1970s (Fig.5), is occupied by sugarcane and cassava crops. Current, areas of paddy field, sugarcane and cassava of Non Jalern and Khon Khwang villages are shown in Table 2.

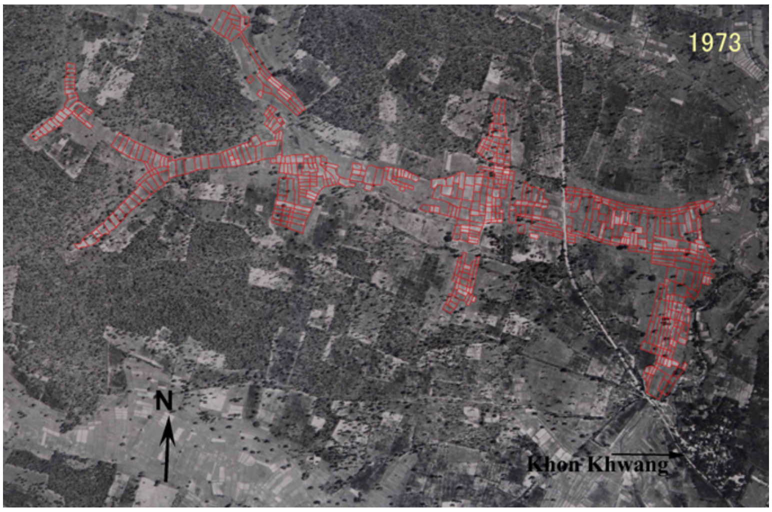

Fig. 5. Aerial photo showing the landscape of the study site that consisted of upland (hills) covered by forests and lowland (valleys) occupied by rain-fed paddy fields in 1973. A solid quadrilateral shows a section of rain-fed paddy fields.

Table 2. Area of paddy field, sugarcane and cassava of Non Jalern and Khon Khwang villages in 2002

Village	Padddy field	Sugarcane	Cassava
Non Jalern	425 (43.1%)	545 (55.3%)	16 (1.6%)
Khon Khwang	1,345 (48.9%)	1,278 (46.4%)	130 (4.7%)

unit: rai 1rai=0.16ha

Farming practice changes and rural community development

We interpreted aerial photos taken in 1968, 1973, 1993, 1996, and 2002 to clarify farming practice changes of the study site. As a result of the interpretation, we found that forests covered most of the upland area in 1973, and rain-fed paddy fields stretched not only into the main valleys, but even into the tributary valleys as well in order that farmers practiced rice farming wherever possible (Fig.5). Also in those days, the cash crop cultivation could not be practiced in the uplands because forests prevented farmers from the cultivation. This suggests that rice was a main farming product for subsistence in the early 1970s. A comparison with the 1993 aerial photos (Fig.6) shows that all the existing forests in1973 had been completely cleared and changed into crop fields by 1993. Such forest reductions occurred throughout the whole country with the most rapid decline between the 1960s and the 1970s (Fig.2). Forests of the study site also rapidly diminished in the mid 1970s because cash crops such as cassava and sugarcane were introduced in the 1970s according to an interview with farmers. At first cassava was the main crop to be introduced to the land converted from forests, but the emphasis shifted to sugarcane after 1990, reflecting the country's changing tendency in the cultivation of cassava and sugarcane (Fig.3). In contrast with the drastic changes in the upland from 1973 to 1993, there was not so much change to the rain-fed paddy fields in the valleys in those days, though these paddy fields increased somewhat (Figs.5 and 6) by expanding cultivated areas from the bottom of valleys to higher ground. The production in the new exploited fields was more unstable than in the bottom fields because the exploited areas were susceptible to drought. However, in order to sustain the population growth, farmers needed to take such a risk. The 1996 photo shows that these paddy fields had begun to decrease slightly because the valley head of the first order was invaded by the crop cultivation. Moreover, the 2002 photo shows that the paddy fields had decreased considerably by then and were distributed only along the main valley bottom because crop fields occupied almost all first order valleys and side slopes where crops can grow (Fig.7). Thus, the expansion or reduction of paddy fields might be closely related to community development. The details will be discussed the next chapter.

According to an interview with farmers in the Non Jalern village, Khon Khwang villagers established the new Non Jalern village in 1993 about 1 km northwest of Khon Khwang. Such village community trans-

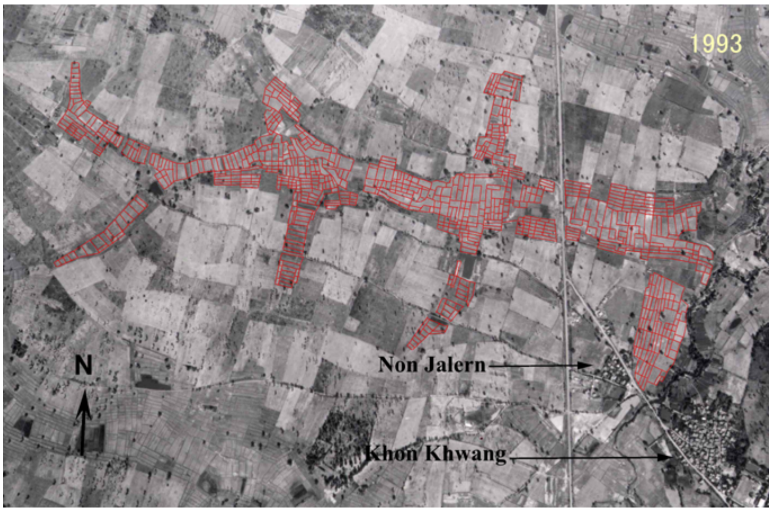

Fig. 6. Aerial photo showing the landscape of the study site that consisted of upland occupied by crop fields and lowland occupied by rain-fed paddy fields in 1993. A solid quadrilateral shows a section of rain-fed paddy fields.

Fig. 7. Aerial photo showing the landscape of the study site that consisted of upland occupied by crop fields and lowland occupied by rain-fed paddy fields in 2002. A solid quadrilateral shows a section of rain-fed paddy fields.

formation can be found in four aerial photos taken in 1973, 1993, 1996, and 2002 (Fig.8). Based on the aerial photos, the estimated number of households in Khon Khwang village was 55 in 1973 and increased to 111 households in 1993 (Fig.9), that is to say, the population growth rate was 102 percent. This rapid population growth resulted in the birth of Non Jalern village in 1993. At that time, there were 35 households in Non Jalern (Fig.9). This suggests that the migration to Non Jalern had begun in the 1980s. By 2002, the number of Khon Khwang households had increased slightly to 137 (the growth rate; 23 percent), whereas Non Jalern's households rapidly increased to 64 in 1993 (the growth rate; 83 percent). The year when the Sawang Samkkhitham temple (Fig.8) was constructed in the village can be used to estimate the birth of the original Khon Khwang village community. A temple is a symbol of unification in a rural community, and the temple must have been built when the rural community was actually unified. According to an interview with a monk of Sawang Samkkhitham temple, it was built in 1940. Therefore, Khon Khwang village was established sometime before 1940.

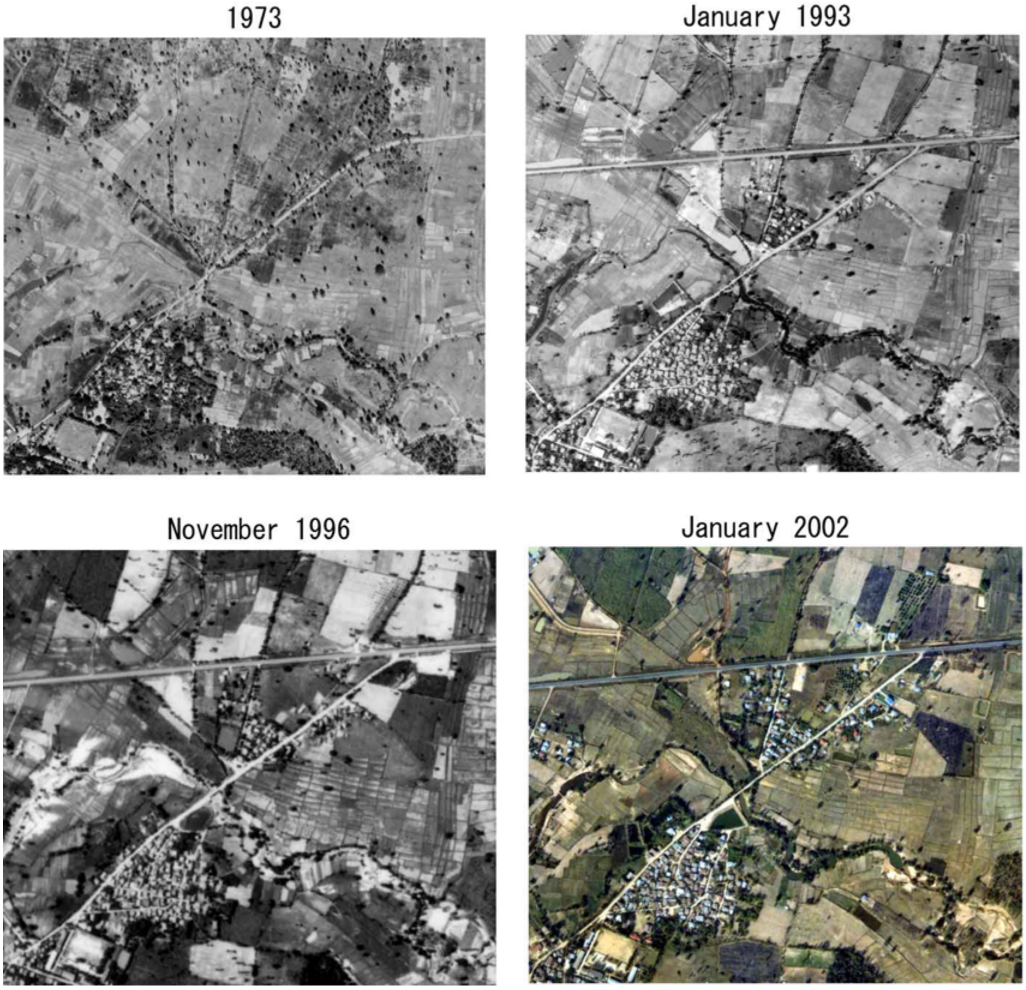

Fig. 8. Aerial photos showing the birth of a new village (Non Jalern) from a mother village (Khon Khwang)

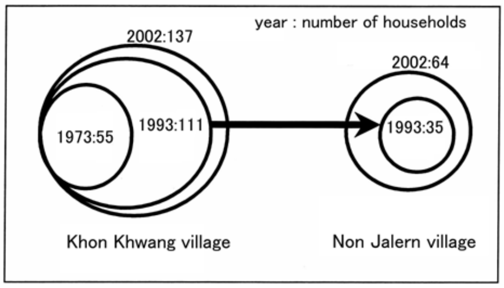

Fig. 9. Changes in the number of households in Khon Khwang and Non Jalern estimated using aerial photos

Relations between farming practices and rural community transformation

In the old days when the upland was covered by forests and rain-fed paddy fields occupied the lowland (Fig.5), rice farming was practiced almost anywhere rice could possibly be cultivated in order to maximize its production despite unsteadiness of the yield, which depends on weather conditions because of rain-fed paddy fields. Forests in the upland remained stable because paddy rice could not grow in the upland; the uplands were non-productive rice areas (Fig.5). Therefore, the population of the village in those days was controlled by the amount of production of subsistence rice in the lowland. Thus, the population in the study

Fig. 10. Severe soil erosion in the cassava field of Khon Kaen Province (taken in October 1999)

site must have remained at almost the same level from around 1940 until 1973, and the site's upland forests remained stable until the early 1970s. However, the introduction of cash crops into the upland in the mid 1970s changed the forests into crop fields and effected the evolution of a new landscape where crop fields covered the upland, while rain-fed paddy fields still occupied the lowland (Fig.6). At the same time, the increased income obtained from the cash crops made the village people wealthy and resulted in the population increase in Khon Khwang village (Fig.9). The growth in Khon Khwang village led to the establishment of the new Non Jalern village in 1993 (Figs.8 and 9). To support this population growth, rain-fed paddy fields in the study site were somewhat expanded (Figs.5 and 6). However, there is a limit to the size of the population that can be fed by the production obtained from its own paddy fields because rice cultivated areas are constrained by the topographical condition even though the efforts to expand the areas are made. If the population exceeds the limitation, additional rice must be introduced from the outside. Judging from the aerial photos, the village people must have abandoned their dependence on their own fields to provide all their subsistence rice since 1996. Unsteadiness of the rice production due to the drought-prone weather must have accelerated the abandonment. From this view, maximum efforts to increase the amount of the rice production might be made in around 1993 (Fig.6). However the efforts could not be maintained because of the pressure of population growth of the study site. Once the abandonment starts, cash crop cultivation is further stimulated and continues to invade wherever possible. This is why the rain-fed paddy fields of the study site decreased considerably in 2002 and were distributed only at the valley bottom (Figs. 6 and 7).

Soil erosion problems in the study site

Typical soil erosion of crop fields on the upland caused by land use and farming practice changes

Farming practice changes to support the population growth of communities introduce a high potential for erosion of the uplands because the replacement of forests with crop fields modifies site hydrology by decreasing the infiltration capacity, and moreover strong rainfall intensity in the region easily exceeds the infiltration capacity of crop fields (e.g., Fig.10) Consequently, the Horton type overland flow, which results from accumulated water that runs down the soil surface, coupled with soil texture (sandy soil, sandy loam soil) that is susceptible to erosion, causes soil erosion in the upland crop fields (Maita it et al.,2002, Maita it et al.,2004). This potential has become a reality in the study site because of the drastic change from forests to crop fields that occurred in the upland in the 1970s. In the study site, cassava was first introduced as the main crop to the land converted from forests, but production has shifted to sugarcane since 1990. Cassava cultivation has a higher erosion potential than sugarcane because cassava provides less cover for the soil surface than sugarcane, so some of the soil erosion shown in Fig.11 must have occurred when cassava was planted as the main crop in the upland. Even though sugarcane cultivation is less susceptible to erosion than cassava, it, too, sometimes caused soil erosion, because the field was laid bare just after harvesting at the end of a three-year (sometimes two-year) crop cycle and was not sufficiently covered when young plants of sugarcane were planted. For example, Fig.11 shows that rainfall at the end of the rainy season in 2004 caused soil erosion at the temporary bare field just after harvesting sugarcane. Also, rainfall at the end of the rainy season in 2001, just one cycle before, caused erosion at almost the same field after harvesting (Fig.11). As mentioned above, this type of erosion resulted from the replacement of forests with crop fields in order to promote the agricultural development of the rural community.

According to Fig.1 and Table 1, the amount of suspended sediment (in other words, off-site erosion)

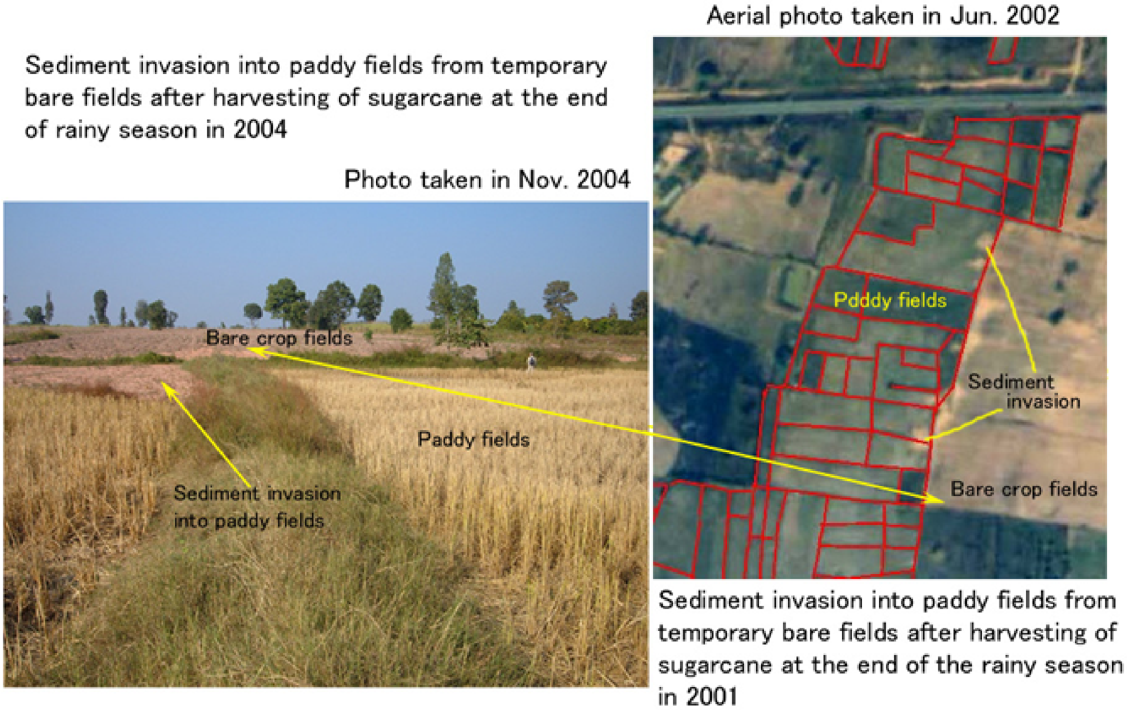

Fig. 11. Soil erosion at the temporal bare field just after harvesting sugarcane and the invasion of eroded soil into paddy fields

of the Chi River basin in which the study site is located, is not always severe though many reports describe that Northeast Thailand has the most severe soil erosion (Thangtam, 1991; Hasegawa, 1992; Tasaka, 1994). A clue to understanding this discrepancy may be in the fact that eroded sediments which originated from crop fields of uplands were deposited in the paddy fields before reaching streams, i.e., paddy fields functioned as a sink for eroded sediments.

Unique soil erosion of the rain-fed paddy fields caused by development of the rural community

Agricultural development generally leads to the improvement of infrastructures in rural communities. Roads are one of the most important infrastructures to support villagers' daily life as well as the development of rural communities. In the study site, the agricultural development that started at the end of the 1960s has not only resulted in the rural community transformation, but also the improvement of roads in the rural community. In comparing two maps of 1/50,000, one of which was published in 1969 and the other was revised in 1992 by satellite imagery, we can find that new roads through communities were constructed based on current road standards, and also main roads that were unpaved in the past were paved by asphalt (Fig.12). When roads that crossed the valleys of rolling hilly land were constructed based on current standards, culverts were installed in the road to prevent floodwaters from overtopping. Thus the development of rural communities due to agricultural development has shifted road standards from a low level to a high level. However current standards do not take account of disposal of the floodwaters flowing down from culverts. Moreover rice farming systems of rain-fed paddy fields do not have drainage systems designed to receive concentrated floodwaters from culverts in the road.

According to an interview with farmers, the tillage for rice farming of the study site began in June, early rainy season, rice planting was conducted in July to August, mid rainy season, and the harvesting was conducted in October to November, late rainy season and early dry season. Rainfall plays an important role for rice cultivation in rain-fed paddy fields in the present as well as in the past. However, we found that heavy rainfall causes sometimes severe soil erosion in rain-fed paddy fields as shown in Fig.13. Fig.13 illustrates that the flood of the late rainy season in 2003 caused soil erosion in the range from the just downstream of the outlets of culverts until the upslope of the deposited rain-fed paddy fields along the temporal water path of the 2003 flood in the study site, and the eroded soil was deposited in the downslope paddy fields. This unique soil erosion was caused by concentrated floodwaters from culverts in the road because there were no facilities for declining the energy of concentrated the waters from culverts and no drainage systems designed to flow the

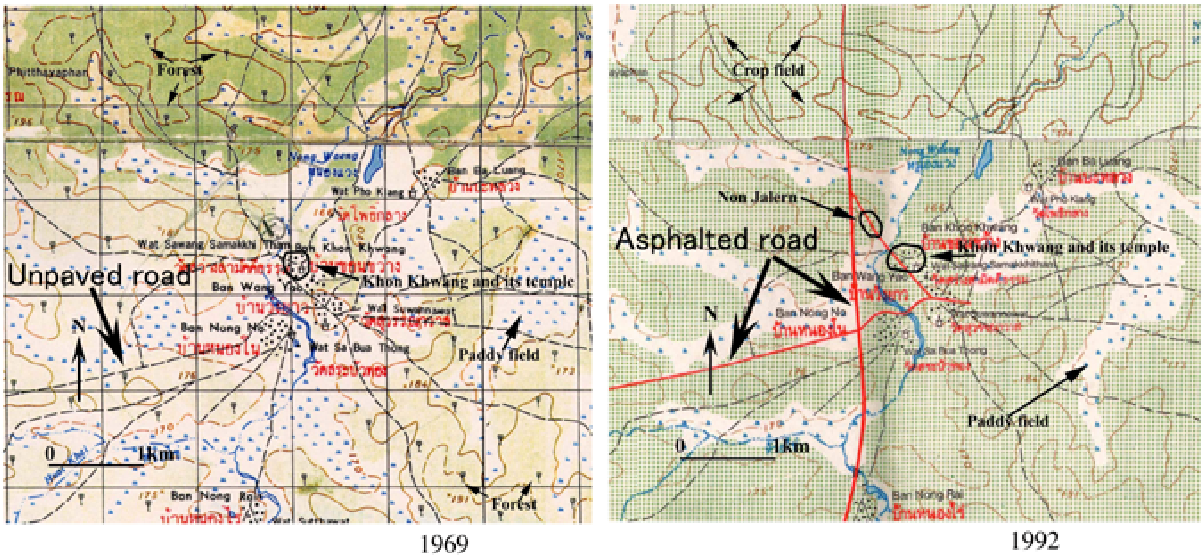

Fig. 12. Improvement of roads due to development of the rural community shown in topographical maps of 1/50,000. broken line : unpaved road constructed under a low level road standards, heavy solid line: asphalted road constructed under a high level of road standards.

waters down safely in the rain-fed paddy field.

In the past days, this type of soil erosion could not occur in the study site. One reason is that floodwaters could not be concentrated by the road, because since the road was constructed based on the low level in the standards at that time, culverts were not installed Another reason is that even if the floodwaters overtopped on the road, their erosive force could not be strong enough to cause soil erosion because the waters could flow diffusively on the road, and their drop distance from the road surface to paddy ground could be relatively short because of the low level of the standards.

As mentioned above, the unique soil erosion results form relations between rain-fed rice farming systems and roads with culverts. If we compare rain-fed rice farming systems in Thailand with rice farming systems in Japan, we can understand the peculiarity of this erosion problem more clearly. For this purpose, we describe briefly rice farming systems in Japan. There are no rain-fed paddy fields in Japan. Paddy fields of Japan are always equipped with a paired irrigation and drainage system in which drainage channels connect to streams. In a road with culverts which crosses paddy fields, the drainage channel system is always installed in the paddy field to absorb floodwaters safely. When flooding occurs, water in the paddy field flows down through the drainage channel system and eventually flows into streams. Therefore the floodwaters can be accommodated by streams if floods are within the magnitude of design floods. In contrast, any drainage systems for floodwaters are not installed in the rain-fed paddy fields of Thailand as mentioned above.

In conclusion, soil erosion problems in rain-fed paddy fields depend on the imbalance between the road improvements due to development of the rural community and rice farming systems of rain-fed paddy fields that remain unchanged in spite of development of the rural community.

Conclusions

Based on the suspended sediment data observed during the past three decades by government agencies, the sediment production rate of Thailand considerably is lower than that of Japan. And suspended sediment loads of Northeast Thailand in which the study site is located, are not always high even though many reports describe severe soil erosion. A clue to understanding this discrepancy may be in the fact that paddy fields functioned as a sink for eroded sediments.

According to the result of a case study of the study site, the introduction of cash crops in the upland starting in the 1970s caused a drastic change in the agricultural landscape, i.e., the former landscape, which was composed of forest-covered uplands and lowlands occupied by rain-fed paddy fields for subsistence rice, has changed into the new landscape formed by the replacement of forests with crop fields in the upland. Agricultural development resulted from the introduction of cash crops promoting population growth in the rural community, and moreover this growth resulted in the birth of Non Jalern village from the mother village, Khon Khwang

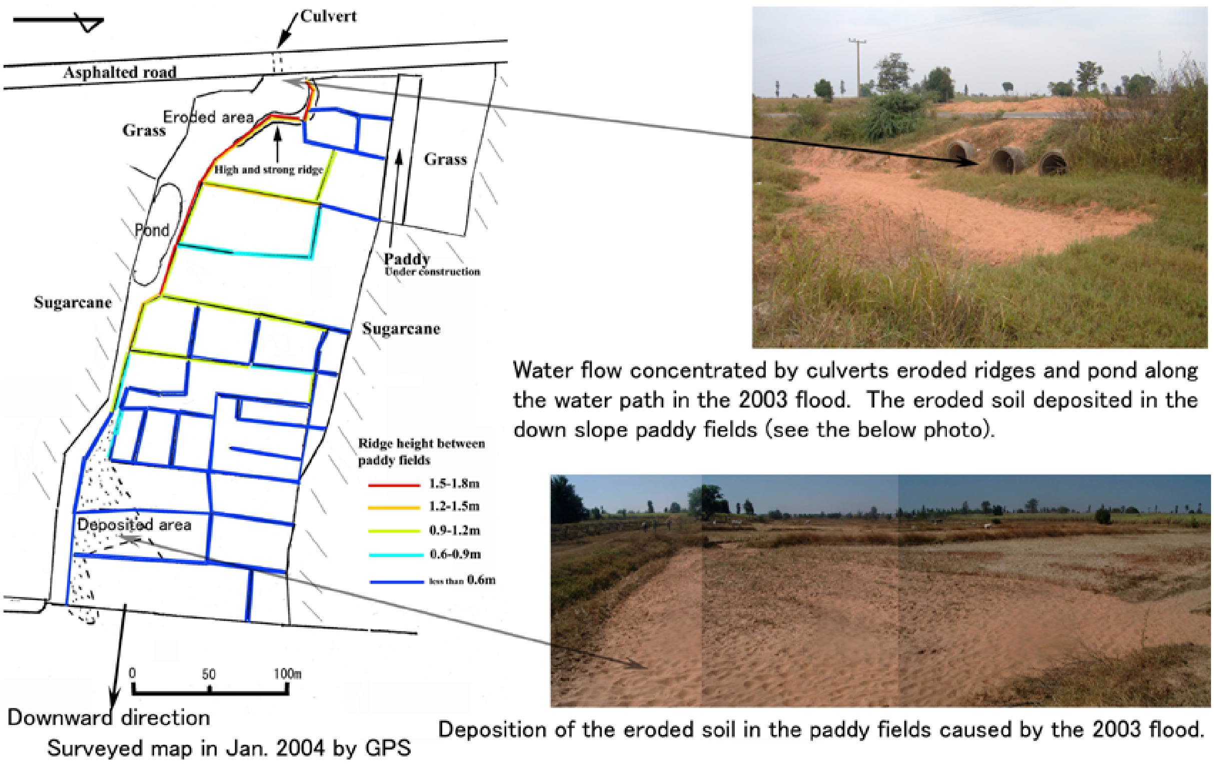

Fig. 13. Soil erosion of rain-fed paddy fields caused by concentrated water flow due to culverts in the road and the deposit of eroded soil in downward rain-fed paddy fields. A solid quadrilateral shows a section of rain-fed paddy fields. The narrow strip of the left-hand side of the map shows temporal water path of the 2003 flood.

in the study site. Such agricultural development caused soil erosion problems in the study site. One is the typical erosion of crop fields in the upland. The other is the unique soil erosion of rain-fed paddy fields in the lowland. Soil erosion of crop fields converted from forests in order to sustain an increase in the rural population was caused by the modification of site hydrology by decreasing the infiltration capacity, coupled with a strong intensity of rainfall in the rainy season and sandy soil. On the other hand, soil erosion of rain-fed paddy fields resulted from culverts in the road that crossed the valley of rolling hilly land, although the paddy fields did not usually cause soil erosion problems. This unique soil erosion was caused by concentrated floodwaters from culverts in the road because there were no facilities for declining the energy of the concentrated waters from culverts and no drainage systems designed to flow the waters down safely in the rain-fed paddy field, in spite of the recent improvement of roads based on shifting from a low level to a high level in the standards accompanied by development of the rural community. In brief, soil erosion problems in rain-fed paddy fields are caused by an imbalance between road improvements due to development of the rural community and rice farming systems of rain-fed paddy fields that remain unchanged in spite of the development of rural community. In conclusion, agricultural development of the study site caused not only the typical soil erosion in crop fields of the upland, but also the unique soil erosion in rain-fed paddy fields of the low land. Both types of soil erosion depend on underlying factors such as agricultural development, rural community transformation, and population growth as well as by direct factors such as rainfall intensity, topographical features, farming systems and road culverts.

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