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Performance of an Agro-forestry System in an Erosion-Prone Area of Northeast Thailand

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ABSTRACT To explore the effective countermeasures against the simultaneous degradation, i.e. soil erosion and loss of bases, of land resources in northeast Thailand, we tested the performance an agro-forestry system at Yang Khi Nok Village, Khuangnai District, Ubon Ratchathani Province. Establishment of agro-forestry system aims at a sustainable management of both cropland and forest.

Pineapple (*Ananas eomosus (L.) Merr*) and kenaf (Thai kenaf, *H. sabdariffa* L. var. *altissma*) were cultivated as cash crop and three rows of fruit tree (*Psidium guajava, Cocos nucifera, Pithecollobium dulce, Punica granitum, Tamarindus indica,* and *Zizyphus jujuba*) were placed among the cash crop rows. Erosion control belt (8 treatments) composed of 3 trees (*Phyllanthus acidus, Eucalyptus camaldulensis,* and *Azadirachta indica*), 3 grasses (*Vetiveria nemoralis, Cymbopogon citratus,* and *Sporobus virginicus*), rice straw mulching, and control was introduced at the lower end of the subplot. A small catchment was also installed to collect the eroded soil.

Soils in this plot has sandy soil texture with a high erodibility. Soil erosion at the current work was not so severe in all treatments. It was suggested that fruit tree planting area prevented soil erosion because this area was not plowed. Tree treatment plots in the erosion control belt, however, showed a greater soil erosion and a loss of bases, compared with others. This was attributed to an insufficient weed growth to cover the ground surface and low soil moisture content at the erosion control belt in the tree treatment plots. However the mass of eroded soils even in the *Eucalyptus* plot gradually decreased during the succeeding years (1997–2000) presumably due to tree crown and/or litter coverage on ground surface. Thus it can be considered that, in terms of erosion control, grass species is better but tree species can also have considerable potential for utilization in the long run.

Key words: agro-forestry system / clay content / loss of bases / Northeast Thailand / soilerosion

During the recent years, alarming land degradation by erosion and salinization have been reported (Pimentel, 1993). Deforestation is one of the predominant reasons behind soil degradation through erosion and salinization. Islam and Weil (2000) reported that deforestation resulted in surface compaction, and significant decreases in silt and clay contents, porosity and aggregate stability, N, fulvic- and labile-C, and microbial biomass-C, levels of soils.

Forest area in northeast Thailand was 42.9% in 1961, which declined to 12.7% in 1994 (Royal Forest Department, 1997). The main causes of deforestation have been caused by the commercial logging and expansion of a cash crop production field. As a result, soil erosion problem became serious in the undulated areas. Areas experiencing erosion rates greater than 30 t ha^{-1} yr^{-1} cover about 30% of

Northeast Thailand (Department of Land Development, 1993). Erosion of topsoil, concomitantly caused a release and/or dissolution of salt interbedded with shallow part of the land cover (geologically, the layer of Mahasaralham Formation). The released salt eventually flowed down to paddy fields (K. Miura, 1990). Department of Land Development (1991) reported that salt affected areas covered about 30% in northeast Thailand.

Agroforestry system has been considered as one of the potential ways of preventing soil degradation. Agroforestry systems have various styles and applications depending on the nature and severity of land degradation. Alley cropping, an agroforestry system, has been effective in minimizing soil erosion (Tacio, 1993; Comia et al., 1994) and soil physical, chemical and biological degradation (Yamoah et al., 1986; Hulugalle & Kang, 1990; Hauser, 1993).

To establish a system for solving the problems of land degradation through soil erosion and loss of bases in northeast Thailand, we designed and tested the performance of some "agro-forestry" systems utilizing cash crop and domestic fruit trees aiming at the sustainable management of both cropland and forests. In addition, fast-growing trees that are useful economically were compared with grasses for their erosion control potentials.

MATERIALS AND METHODS

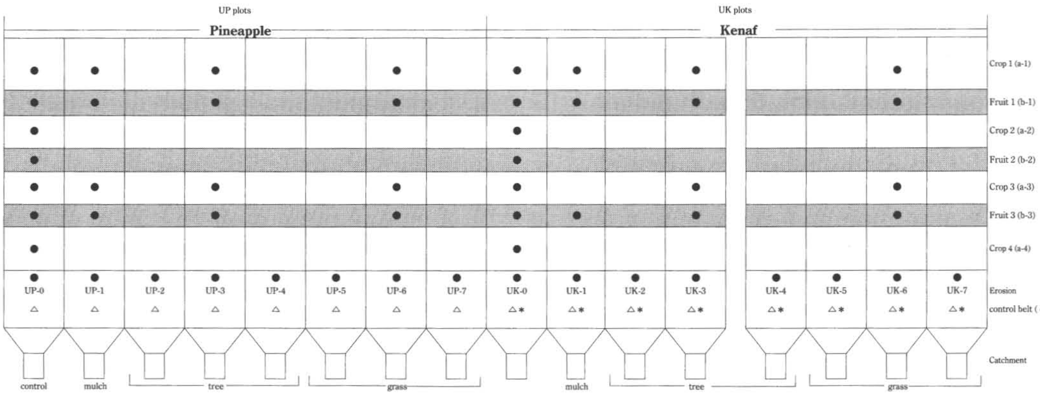
Study site

The study was conducted at Yang Khi Nok Village, situated at latitude 15°26′N and longitude 104°32′E, Khuangnai District, Ubon Ratchathani Province, about 40 km northwest to Ubon Ratchathani City. The difference in altitude within the whole site was around 1.5 m and that within the study plot was around 1.0 m. Climatologically, this region belongs to Köppen's Aw (tropical wet and dry climate) (Thailand Development Research Institute, 1987). The approximate altitude of the site was 125 m above sea level. The lands in this region are mostly utilized for paddy. After the reconnaissance survey in 1995, an experimental plot was demarcated in 1996, on the toposequence from the hedge of secondary forest to paddy field in the down slope, slightly sloping (1.5%) to the south. Once the rainwater becomes abundant or the lowest part of paddy field is flooded, the owner used this land for paddy. However, this land had not been utilized every year due to water shortage or high salinity.

Arrangement of the plots

Sixteen subplots, each with the dimension of 5.5 m x 25 m were laid out. The cash crops, such as pineapple or sweet corn and kenaf, and six locally grown fruit trees (*Psidium guajava, Cocos nucifera, Pithecellobium dulce, Punica granitum, Tamarindus indica, Zizyphus jujuba*) were used in the system. Pineapple or sweet corn planting plot and kenaf planting plot are abbreviated as UP and UK plot, respectively. *Psidium guajava* and *Tamarindus indica* in UP plot and *Pithecellobium dulce* and *Punica granitum* in UK plot were selected for further investigation and other fruit trees were cut down during November 1997. These fruit trees were selected based on their good growth and owner's preference as well.

Four rows of crops and three rows of fruit trees were placed alternatively within the higher part of a subplot. An erosion control belt comprising 3 trees (*Phyllanthus acidus, Eucalyptus camaldulensis*, and *Azadirachta indica*), 3 grasses (*Vetiveria nemoralis* (Roi Et), *Cymbopogon citratus,* and *Sporobus* *virginicus*), rice straw mulching, and control was placed at the lower end of the subplot. The suffix 0, 1, 2, 3, 4, 5, 6 and 7 was used with UP or UK plot to represent the type of erosion control belt used with the subplot as described in Fig. 1–1. A small catchment (2 m in length, 1 m in width, and 1 m in depth) was installed to collect the eroded soil during rainy season. An elaborate design of the plots is shown in Fig. 1–1.



Erosion control treatment number

0: Control	2: Phyllanthus acidus (Star berry)	5: Vetiveria nemoralis (Vetiver grass)
1: Rice straw mulch	3: Eucalyptus camaldulensis (River erd gum)	6: Cymbopogon citratus (Lemon grass)
	4: Azadirachta indica (Neem tree)	7: Sporpbus virginicus (Dixie grass)

● : soil sampling point △ : gypsum bloks * : soil temperture

Fig.1–1. Soil sampling and monitoring point

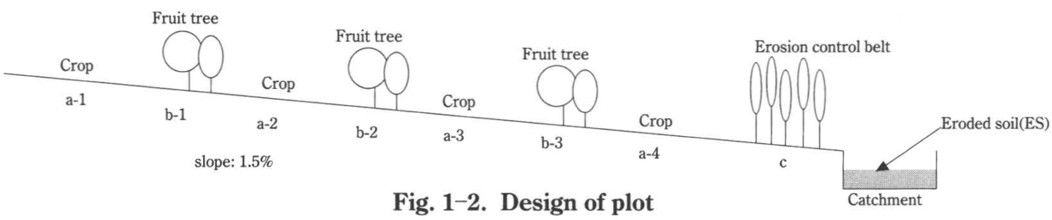


Fig. 1–2. Design of plot

Selection of crops and erosion control plants

Pineapple, corn and kenaf are recommended as salt-tolerant plants by Thai government. Pineapple sold in the local market in mostly produced in the other regions of Thailand, since it is seldom cultivated in this province. Sweet corn and fodder corn are cultivated in 742 ha and 3982 ha, respectively. Kenaf was cultivated in 13,388 ha in 1995 (Ubon Ratchathani Provincial conclusion, 1995). About 95% of kenaf is produced in Northeast Thailand. In the recent years, kenaf plantation area in the whole country has been declined for 205,280 ha in 1986 to 72,320 ha in 1995 (Ministry of Agriculture & Co-operatives, 1996) due to its unstable market price. However, we considered kenaf as an appropriate choice in a field less suitable for other crops.

Trees for erosion control included in this study were fast growing ones. *Phyllanthus acidus* is a member of the family *Euphorbiaceae* having edible fruit and fairly hard and durable wood, if seasoned. Plantations of *Eucalyptus camaldulensis*, a cash crop, have replaced portions of native forests utilized and managed by many rural communities across Northeast Thailand. The multi-purpose tree, *Azadirachta indica* is native to parts of South Asia is a member of the *Meliaceae* family. Its deep root system is well adapted to retrieve water and nutrients throughout the soil profile, but this deep root system is very sensitive to waterlogging (National Research Council, 1992). We expected that these trees would prevent salinization in the down slope by lowering of groundwater table due to vigorous water absorption by the deeper root systems.

Vetiver grass is currently promoted as a soil and water conservation tool in a number of countries. In on-station research trials in India, vertiver reduced both surface runoff and soil loss, while increased crop productivity (World Bank, 1991). Yudelman et al. (1990) evaluated vertiver's performance and potential for soil and water conservation, comparing it with a range of alternative grass species. Vetiver scored high marks for its resistance to adverse conditions, under a wide range of climatic conditions, and ease of establishment. In comparison, *Cymbopogon nardus* (citronella) were close to but still below vertiver's performance. However, the same genus of citronella, *Cymbopogon citrates* (lemongrass), is very popular grass for the edible stem and lemongrass oil in Thailand. So we selected this one. The fodder crop, *Sporobus virginicus* can grow well in saline soil enduring salinity levels more than 8dS m^{-1}.

Soil analysis

Twenty-seven soil samples from both UP and UK plot were collected from surface 0–5 cm layers before planting and after harvest. Five 100 mL soil samples per sampling point were collected and mixed into one composite sample. Sampling points are indicated in Fig. 1. The physicochemical properties of soils were analyzed for pH, electrical conductivity (EC), exchangeable cations (Ca, Mg, K, Na), cation exchangeable capacity (CEC), total carbon (T-C), total nitrogen (T-N), available phosphorus (Av-P) and particle size distribution. The eroded soil particles were also analyzed for the above parameters. Soil pH was measured in a soil to water ratio of 5 g to 25 mL. EC was measured before pH measurement. Exchangeable cations (Ca, Mg, K and Na) were extracted with 1 M-ammonium acetate (pH 7.0) in a soil to solution ratio of 5 g to 25 mL by reciprocal shaking followed by centrifugation. The amounts of Ca, Mg and K were determined by atomic adsorption spectrophotometry, and that of Na by flame photometry (Shimadzu, AA-610S). Then, the residue was washed once with deionized water once and twice with 990 g L^{-1} CH_3CH_2OH to remove the excess salt. The adsorbed ammonium was exchanged twice with 100 g L^{-1} NaCl solution through reciprocal shaking for 1h followed by centrifugation for 10 min at 179 G. The ammonium ion content in the supernatant was determined by titration method after Kjedahl distillation and taken as CEC. T-C and T-N were determined by a dry combustion method with NC-Analyzer (Sumitomo, Sumigraph NC-80). Av-P was extracted with 0.002 M H_2SO_4 for 30 min and the content was determined by the molybdenum blue method. Particle size distribution was determined by the pipette sampling method after wet decomposition of organic matter with 60 g L^{-1} of hydrogen peroxide and dispersion with the addition of 1 M NaOH to raise the solution pH to 9.5.

Monitoring of site characteristics

Maximum and minimum air temperature, precipitation, and pan evaporation were recoded daily until

November 1997, and weekly thereafter. Soil temperatures at 0, 5, 10, and 20 cm depth were recorded daily until November 1997, and then weekly until July 1998. Soil moisture (gypsum block method) at 10 and 20 cm depth were recorded weekly at the erosion control belt in UK plot. EC and pH of the soils both inside and outside the plots were checked monthly at some selected points.

Estimation of the mass of eroded soil particles

After the rainy season was over, i.e. in November the eroded soil mass was air-dried in the catchment and litter were removed by hand. The total weight of the eroded soil mass was determined.

Raising the crops and recording their performance

Pineapple: Slips of pineapple were planted in June 1996 at 50 cm x 30 cm and 70 cm x 30 cm spacings, alternately. Before planting, 6 t ha^{-1} of farmyard manure and 300 kg ha^{-1} of chemical fertilizer (15-15-15) were applied. A second fertilization at the rates of 6 t ha^{-1} of farmyard manure and 300 kg ha^{-1} of chemical fertilizer (14-14-21) was made in March 1997.

Pineapple was harvested in August 1997. The fresh weights of fruits, crowns, stalks, leaves and roots were determined from 1 m^2 (6 hills) harvest area with 4 replications from each subplot. The sub-samples for determining dry weights were taken from every plant parts and were dried out at 60℃ until a constant weight was reached.

Corn: Since the growth of pineapple was poor in 1997 due to bad drainage in the rainy season, pineapple was replaced with sweet corn in 1998 and 1999. In the case of corn, 8 t ha^{-1} of farmyard manure and 400 kg ha^{-1} of chemical fertilizer (15-15-15) were applied before planting. On an average, 4 corn seeds/hill were sown at the same spacing as pineapple in June 1998 and 1999. The final plant density (6 hills/m^2) was achieved by hand thinning to one plant per hill one to two weeks after germination.

The fresh and the dry weights of the different plant parts (ear, husk, stem, leaf and root) were measured following the same method as adopted for pineapple.

Kenaf: For kenaf, 8 t ha^{-1} of farmyard manure and 400 kg ha^{-1} of chemical fertilizer (15-15-15) were applied before planting. About 6 seeds of kenaf were sown per hill maintaining the same spacing of pineapple in June every year. The final plant density (6 hills/m^2) for kenaf was achieved by hand thinning to 4 plants per hill one to two weeks after germination. Weeding and the application of agricultural chemicals were done as and when necessary.

In October every year, the kenaf was harvested. The fresh weight of stem, branches and roots of kenaf were determined in 1 m^2 (6 hills) sampling area with 4 replications from each subplot. The sub-samples for measuring dry weights were taken from every plant part and were dried out at 60℃ until a constant weight was reached. The stem was retted for 20 days and the kenaf fibers were separated from the stems.

Crop yields were calculated for the crop planting area excluding the area that occupied by fruit trees and erosion control plants.

Estimation of biomass of erosion control plant and weed

The above ground biomass of the erosion control plant and weed from each treatment of erosion control belt were measured in November 1998. Weed was mowed in 1 m^2 and the fresh weight was measured.

In the grass plot, weed and grass were mowed together, separated to their individual fraction and their fresh weights were measured. The sub-samples from every plant and weed were dried out at 60℃ until a constant weight was reached. The results were expressed on oven dry basis. For 3 trees, stem diameter at ground surface (D_0) and tree height (H) were measured for each tree. For estimation of the biomass of tree the following allometric equation was used. This equation was solved using the data of *Eucalyptus camaldulensis* in September 1999.

$W=a\ (D_0^2H)^b$

$a=6.0669 \times 10^{-5}$, $b=1.0693$

$r^2=0.923$

W, the above ground biomass (kg dry weight); D_0 (mm); H (m)

RESULTS AND DISCUSSION

Climate

Average of monthly maximum and minimum air temperature for 3 years (1997, 1998 and 1999) were 35.3℃ and 17.3℃, respectively. Annual precipitation and rainy days were smaller than those in the past 7 years from 1990 to 1996 (Table 1). However, since there were more than 100 mm of monthly precipitation during the growth period of kenaf (from June to October) (Fig. 2), the crop did not experience a severe draught.

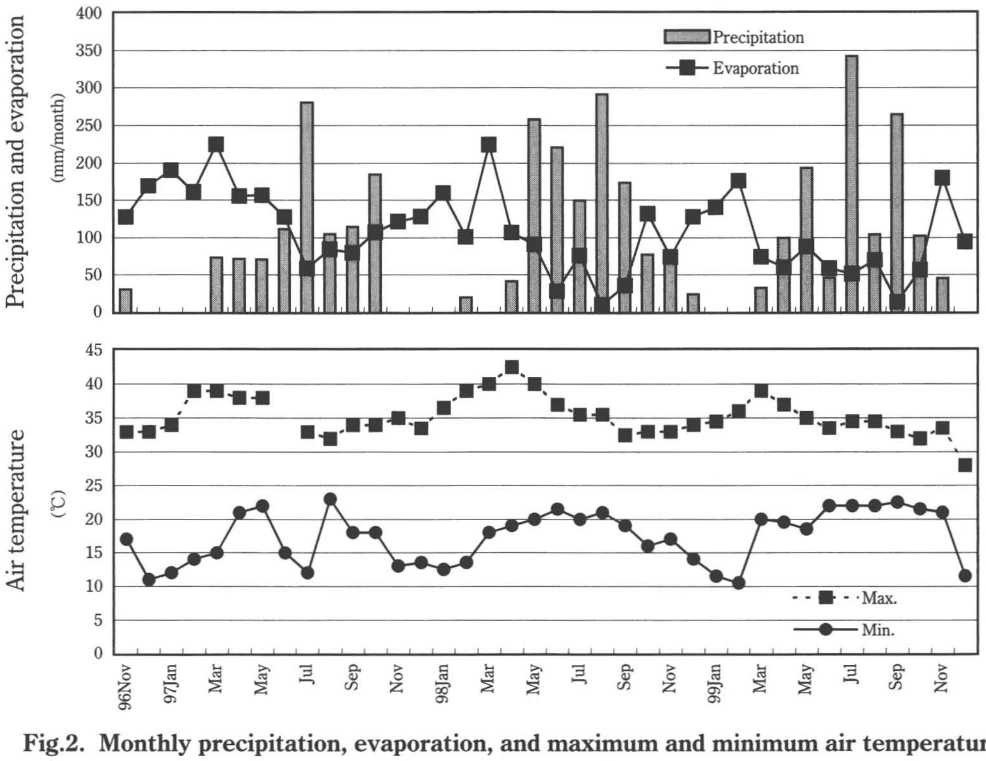


Fig.2. Monthly precipitation, evaporation, and maximum and minimum air temperature

Table 1. Annual precipitation, rainy days and evaporation at the experimental plot

	1997	1998	1999	Average of past 7 years (1990-1996)*
Precipitation (mm)	1027	1283	1215	1477
Rainy days	66	80	95	115
Evaporation (mm)	1640	1135	1062	

*Center for Agricultural Statistics, 1995

Soil temperature and moisture

Fig. 3 shows the monthly average of soil temperature in UK-1 (Mulching), UK-3 (*Eucalyptus camaldulensis*) and UK-6 (*Cymbopogon citratus*). In the dry season (November to March), soil temperature decreased with depth gradually, while in rainy season, it did not change greatly among different depths. Although there were no clear differences in soil temperature among different treatments, the differences between the maximum and minimum soil temperatures at surface in the three treatments were 5.4, 8.9 and 60℃ at UK-1, UK-3 and UK-6, respectively. Soil temperature could be easily affected by direct solar radiation due to little weeds under the trees at UK-3. Mulching treatment appeared as effective to reduce the surface temperature of soils, where the maximum temperature was always maintained below 35℃. Similar observations were noted in the southern part of Thailand by Sakurai et al. (1991) and in the southern Cameroon by Hulugalle et al. (1994).

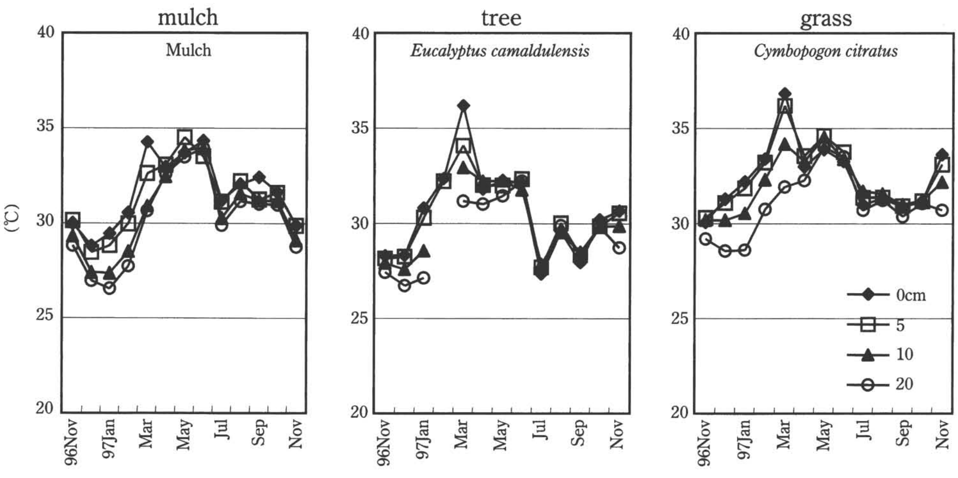


Fig. 3. Monthly average of soil temperature at erosion control belt in UK plot from November 1996 to November 1997

Fig. 4 shows soil moisture represented by the resistance value of gypsum block. The available water (from pF 1.7 to pF 4.2) ranges from 7.7 to 90 kΩ in the resistance value. In dry season, the resistance value at 20 cm depth was generally lower than that at 10 cm depth, indicating that the surface part of soil was drier than the deeper part. However, mulching treatment showed the resistance value at 10 cm within the range of available water and there was little difference between 10 cm and 20 cm depth even in the dry season except the end of dry season, i.e. from12 to 16 March, 1999. Mulching as soil cover not only protects surface soil from the impact of water splash leading to soil erosion but

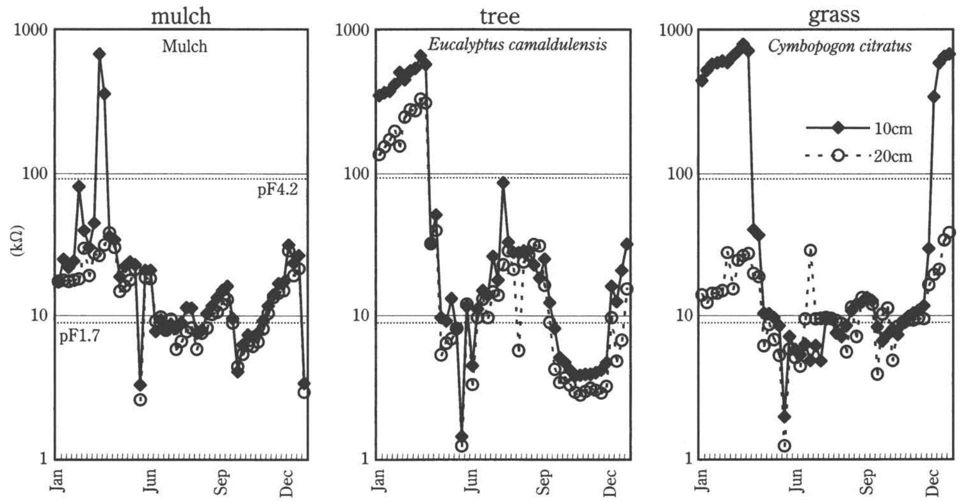


Fig. 4. The resistance of gypsum block at erosion control belt in UK plot in 1999

also improves microclimatic conditions by lowering soil temperature, minimizing temperature fluctuations, and increasing soil moisture (Sakurai et al, 1991; Hulugalle and Ndi, 1994). At the tree sites (e.g. *E. camaldulensis*), the resistance values at 20 cm were greater than 90 kΩ (pF 4.2), presumably due to considerable water uptake from deeper soil depths by tree roots compared with weed roots. This would be the other reason for poor weed growth under the *Eucalyptus* plantation. After *E. camaldulensis* was cut down on September 17, 1999, soil moisture content in this plot became higher than the other plots because the vigorous water absorption by *Eucalyptus* trees was probably ceased.

Soil physicochemical properties

Miura et al. (1990) characterized all the upland and lowland major soils of Northeast Thailand as with sandy texture and very low base status. Similar results were obtained in this study area. The soil texture in this plot was sand with sand fraction accounted for more than 90% of the soil separates (Table 2). Clay content was lower than 3.2%. It is very low compared with the results of Miura et al. (1990) who reported clay contents ranging from 4.5 to 17.8%. The ratio of water dispersible fraction to the complete dispersible fraction of clay and silt were 43 and 101%, respectively (Table 2). Even though clay and silt content of soils was low, these fractions had a high dispersibility, and therefore a high erodibility. The amounts of aluminum and iron extracted with acid-oxalate (Alo and Feo) and with dithionite-citrate-bicarbonate (Ald and Fed) were very low (Table 3).

Table 2. The particle size distribution and dispersion ratio of original soil (June 1996)

	Water dispersion		Complete dispersion				Dispersion ratio*	
	C	Si	C	Si	FS	CS	C	Si
	%							
Average	0.9	5.3	2.2	5.3	78.9	13.7	43.4	101.6
Max.	2.4	8.2	3.2	9.3	82.2	24.4	110.5	180.0
Min.	0.1	3.0	1.2	3.0	68.5	8.3	4.2	71.4
CV	52.3	25.6	22.3	25.2	3.5	25.3	55.7	19.5

Abbreviations: C, Clay (<0.002mm);Si, Silt (0.02–0.002mm); FS, Fine Sand (0.2–0.02mm);
CS, Coarse Sand (2–0.2mm)

* : Water dispersion / Complete dispersion × 100

Table 3. Sesquioxide of original soil (June 1996)

sample	Tamm extraction Alo	Feo	Sio	DCB extraction Ald	Fed	Sid	Alo/Ald	Feo/Fed	Sio/Sid
	g kg^{-1}								
Av.	0.028	0.120	0.004	0.114	0.966	0.467	0.24	0.13	0.01
Max.	0.075	0.292	0.014	0.146	1.667	0.768	0.57	0.32	0.04
Min.	0.004	0.016	0.001	0.094	0.684	0.221	0.04	0.02	0.00
CV	79.1	80.5	87.1	10.1	23.2	26.6			

Abbreviations: Alo, Feo and Sio, acid-oxalate exchangeble Al,Fe andSi
Ald, Fed and Sid, ditionite-citrate-bicarbonate exchangeble Al,Fe and Si

The soils showed an acidic reaction throughout the experimental period, with pH values ranging from 4.66 to 6.18. In original soils, the values of EC and CEC, the content of available phosphorus, total carbon and total nitrogen were also very low (Table 4).

Table 4. Original soil chemical properties (June 1996)

	EC dS m^{-1}	pHw	Exchangeable cations cmol(+) Kg^{-1} Ca	Mg	Na	K	CEC	Av. P mg Kg^{-1}	T-C g Kg^{-1}	T-N g Kg^{-1}
Average	1.29	5.01	0.13	0.04	0.01	0.03	0.91	1.50	2.47	0.25
Max.	2.50	6.18	0.45	0.13	0.04	0.16	1.30	5.83	3.50	1.93
Min.	0.74	4.66	0.04	0.00	0.00	0.01	0.53	0.90	1.42	0.12
CV	30.3		68.4	67.6	69.2	85.6	22.3	44.1	20.6	94.7

Abbreviations: EC, electric conductivity; pHw, pH measured in water; CEC, cation exchange capacity;
Av.P, available phosphorus; T-C and T-N, total carbon and nitrogen content

The soils are Typic Paleaquults (Soil Survey Staff 1992). Ohta and Effendi (1992a, b) and Ohta et al. (1993) reported the properties of Ultisols in Indonesia. Because soil properties largely depend on clay content, they characterized the soils based on three different textural categories, such as "coarse" with clay content less than 35%, "medium" between 35 to 50%, and "fine" higher than 50% at many points of the profile. According their classifications, our study site could be classified as "coarse" soil type. They reported that coarse soil of Ultisols have the lower values of total C, N and P, exchangeable Ca and Mg and CEC, and that the physical properties of coarse soil were inferior to fine soil along with poor internal drainage characteristics. Soils in our study site showed similar properties.

The distribution of clay and silt contents, CEC and exchangeable cations along the slope

The distribution of clay and silt content along the slope is shown in Fig. 5. Clay and silt content of both UP-0 and UK-0 in 1997 were higher than that in 1998. In 1998, both clay and silt content of the cropping area (a-1, a-2, a-3, a-4) and fruit tree planting area (b-1, b-2, b-3) slightly decreased and these of ES was extremely high. Probably, more amounts of clay and silt selectively moved away to ES because of the better condition for dispersion of clay and silt with high water content. The change of clay and silt content in 1996 to 1997 can not be explained clearly.

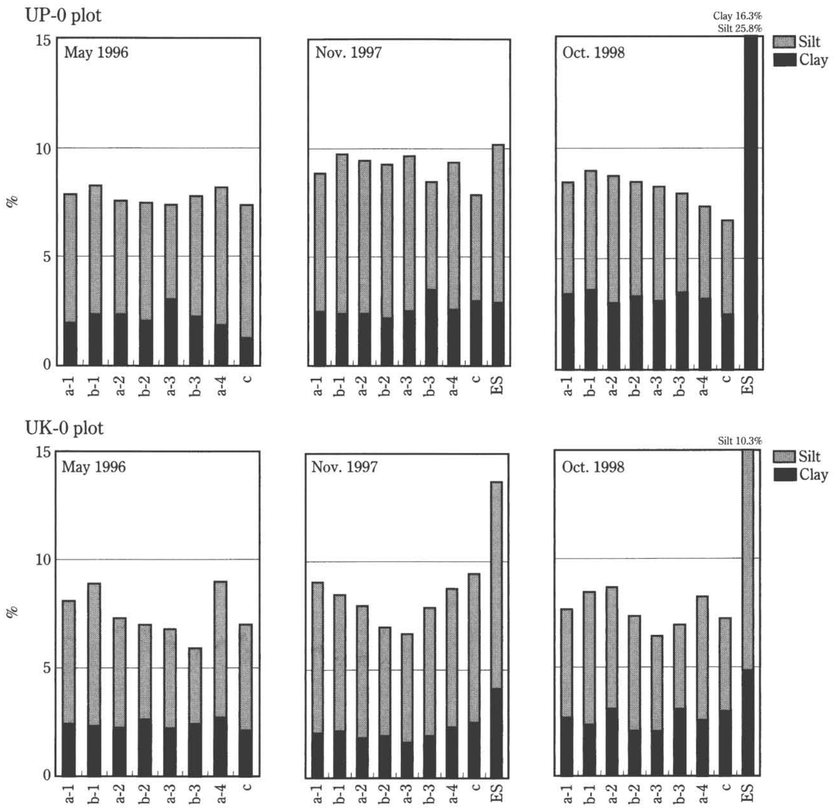


Fig. 5. The distribution of clay and silt content in control plot (UP-0 and UK-0)
(Abbreviations are same as in Fig. 1–2.)

Fig. 6 shows the distribution of exchangeable cations and CEC along the slope in UP-0 and UK-0 after harvest in 1997 and 1998. In UP plot, exchangeable cations were higher than that in UK plot, probably because UP plot was located at slightly lower position than UK plot. Rainwater tended move from UK plot toward UP plot through under the fence of each plot, resulting in the relative accumulation of exchangeable cations in the slightly lower place, i.e. the cropping area, compared with the fruit tree planting area in 1997. On the other hand, in 1998, the flooded water covered the entire UP-0 plot for several weeks after planting and therefore fruit planting area did not function to trap the water and nutrients, resulting in the even distribution of exchangeable cations among UP-0 plot.

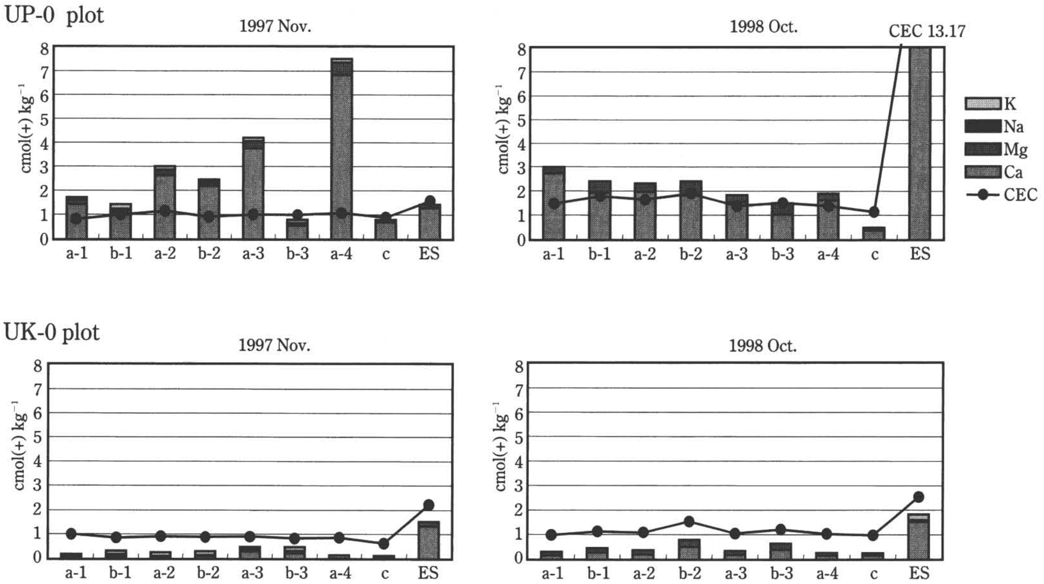


Fig. 6. Cation exchange capacity and exchangeable cations (Ca, Mg, Na, K) of control plot (UP-0 and UK-0)
(Abbreviations are same as in Fig. 1–2.)

UK plot had higher total exchangeable bases in the fruit tree planting area than in the cropping area. It was suggested that fruit tree planting area trapped water and nutrients because this area was not plowed after planting.

The exchangeable cations, CEC, clay and silt contents in the eroded soil mass were higher than those in the planting area because clay and silt fractions, in particular, were eroded from the upper part and deposited in the catchment. Eroded soil mass transported with surface run-off water has long been recognized to be enriched with silt and clay particles, organic carbon, nutrients and other associated chemicals when compared with the in-situ soil (Sharpley, 1985; Young et al., 1985; Palis et al., 1990).

Soil erosion rate and clay content, the amount of base loss

The soil erosion rate in all treatments was not so severe (Table 5). In Nigeria when cassava was planted on a land with 1% slope, the soil erosion rate was 3 t ha^{-1} yr^{-1} (Aina et al., 1977). In USA, the soil erosion rate of corn plantation with 2% slope was 10 t ha^{-1} yr^{-1} (Pimentel et al., 1993). The soil erosion rate in our study area was less than 2 t ha^{-1} yr^{-1} even in the first year 1997. Tree treatment plots (treatments No. 2, 3 and 4) showed greater soil erosion, compared with the other plots. This can be accounted by the less abundant weed growth under trees to cover the ground surface (Table 6) and low

Table 5. The soil erosion rate (t ha^{-1} yr^{-1})

		UP plot				UK plot			
	Treat. No.	1997	1998	1999	2000	1997	1998	1999	2000
control	0	1.00	0.19	0.51	0.19	1.03	0.50	0.57	0.41
mulch	1	0.33	0.26	0.23	0.28	0.90	0.28	0.31	0.52
tree	2	1.14	0.16	0.75	0.73	1.44	0.47	0.68	0.60
	3	1.91	0.85	0.72	0.43	1.89	0.64	0.90	0.30
	4	0.80	0.32	0.66	0.74	0.41	0.25	0.20	0.29
grass	5	0.73	0.27	0.50	0.24	0.63	0.52	0.34	0.59
	6	0.52	0.25	0.51	0.49	0.68	1.02	0.74	0.56
	7	0.81	0.18	0.39	0.38	1.01	0.60	0.88	0.64

Table 6. The above ground biomass of weed and erosion control plant in each erosion control block (oven dry basis), Nov. 1998

		UP plot			UK plot		
	Treat. No.	Weed	CP	Sum	Weed	CP	Sum
		g m^{-2}					
control	0	834	—	834	437	—	437
mulch	1	809	—	809	380	—	380
tree	2	453	76	529	332	114	446
	3	365	9975	10340	458	13273	13731
	4	495	126	621	239	285	524
grass	5	0	3177	3177	0	1237	1237
	6	855	204	1059	242	93	335
	7	1077	0	1077	221	0	221

CP, erosion control plant

soil moisture content at erosion control belt (Fig. 4). In the erosion control belt where *E. camaldulensis* or other trees were planted, surface and subsurface soils became drier compared with other plots. If the soil becomes very dry and the intensity of rainfall becomes high, soil aggregates break down quickly by slaking. As a result, infiltration capacity reduces rapidly and runoff can occur on very smooth surfaces even after only a few millimeters of rain (Le Bissonnais, 1990). UK-6 and UK-7 in 1998 and 1999 also experienced greater soil erosion because the grass could not grow due to scarcity in soil water. However, soil erosion rate decreased gradually from 1997 to 2000 even at tree treatment plots. This phenomenon would be a result of root mat formation, development of tree crown or surface coverage by the plant litter.

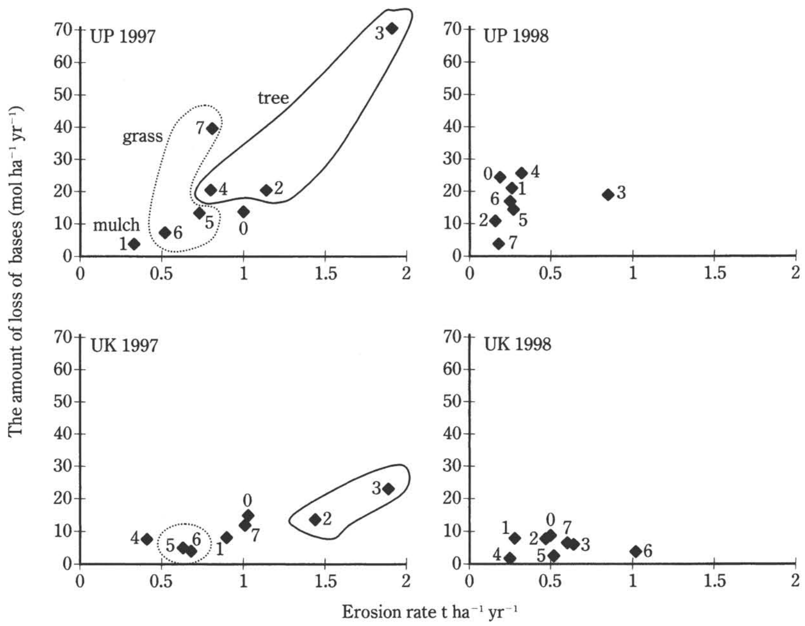


Fig. 7. Relationship between erosion rate and the amount of loss of bases (Ca, Mg, Na and K). The figures indicate the treatment number in erosion control belt.

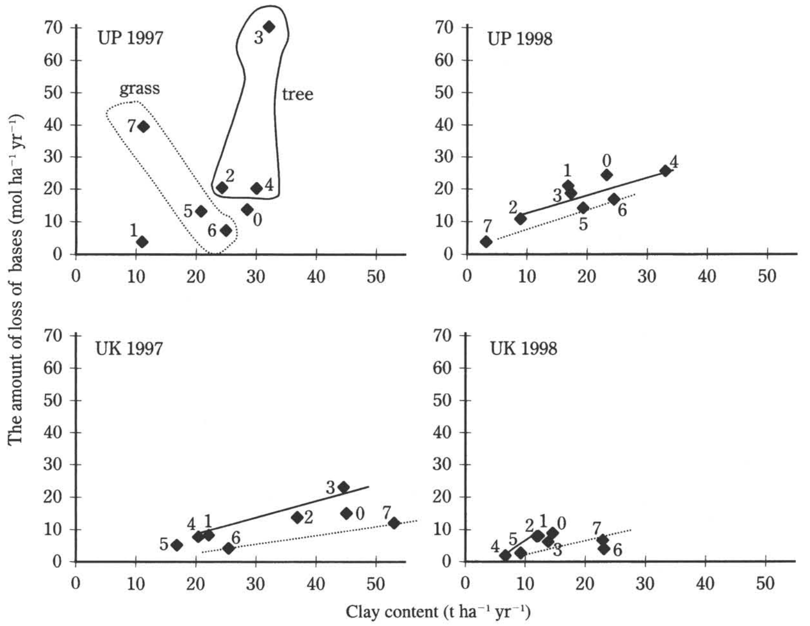


Fig. 8. Relationship between clay content in eroded particle and the amount of loss of bases. The figures indicate the treatment number in erosion control belt.

The relationship of erosion rate with the amount of bases lost is shown in Fig. 7. The amount of bases lost from the crop and fruit tree plantation area could be estimated from exchangeable cations (Ca, Mg, Na and K) in the eroded soil mass deposited in the catchment. The bases lost increased with the erosion rate. For UP plot in 1998, the loss of bases was higher even with a lower erosion rate. Mermunt et al. (1997) described that the reduction in splashed soil materials can be explained by the development of a water film on surface that reduces the impact of raindrop. As UP plot had undergone a flooded condition during rainy season, it was assumed that soil loss decreased due to a water layer reducing the impact of raindrop. On the other hand, overflowed water would have carried the fine particles and organic matter from the upper part of the plot.

The relationship of clay content in eroded soil mass to the amount of the loss of bases is shown in Fig. 8. Among the treatments in the erosion control belt, tree plots experienced a greater loss of bases than grass plots, even though they had similar clay content.

Crop yield

The yield of both pineapple and corn were extremely poor owing to flooded condition during cultivation period. Thus, we will mention only kenaf yield (Table 7). The numbers of stalk per unit area decreased

Table 7. Numbers of stalk in 1m^2 and biomass of kenaf

	No.Stalk	Biomass(oven dry basis , t ha^{-1})				Fiber yield	Height
	m^{-2}	Stalk	Branch	Root	Total	(t ha^{-1})	(cm)
1996	26.2	3.10	0.78	0.43	4.32	0.88	n.d.
1997	21.3	6.94	1.71	0.94	9.59	1.46	242
1998	21.9	7.60	1.59	1.03	10.22	1.64	277
1999	17.5	9.97	1.42	1.05	12.43	2.02	283

from 26.2 m^{-2} in 1996 to 17.5 m^{-2} in 1999. However, the biomass of stalk increased three times from 3.10 t ha^{-1} in 1996 to 9.97 t ha^{-1} in 1999. The yield of kenaf fiber (bast fiber) was 0.88, 1.46, 1.62 and 2.02 t ha^{-1} in 1996, 1997, 1998 and 1999, respectively. Although the yield in 1996 was not satisfactory compared with the national average of Thailand (1.28 t ha^{-1}) (Ministry of Agriculture & Co-operatives, 1996), it increased gradually until 2000. Because fruit tree planting area had not been plowed throughout the experiment and weeds had covered the ground surface at this area, this area can be worked as the area for the prevention from soil erosion. This may lead to a slight increase in soil fertility associated with a constant increase in kenaf yield. The difference among the treatments in the erosion control belt was not clearly observed.

Agro-ecological Implications

During the 3-years experimental period, the annual precipitation was lower than the average of the past 7 years in Ubon Ratchathani province. However, since there were optimum/expected rainfall during the growth period of kenaf, the crop did not exposed to a severe draught.

In the mulching treatment, soil temperature and soil moisture was maintained favorable for crop growth through out the year. However, the effects of mulching on soil fertility and kenaf yield were not significant in this experiment.

Tree treatment plots had little weeds covering the ground surface at erosion control belt and this might be a predominant cause of high erodibility of tree treatment plots, especially, in the *E. camaldulensis* treatment. In addition, tree treatment plots showed a greater loss of exchangeable bases than grass treatment plots. However, Miura et al. (1990) described that *Eucalyptus* plantation was promising to prevent salinization through suppressing the saline seepage water due to the very high transpiration rate of *eucalyptus* trees, and consequently lowering of groundwater table in the foot slopes or the low-laying land. It is anticipated that their results would be applicable in the large-scale topographical sequence. Although *Eucalyptus* plantation may not be suitable for preventing soil erosion, it would be effective for preventing salinization in the lowland within large area. Study of this aspect, which is in progress, inherits vital agro-ecological significance.

Tree treatment plots, especially *E. camaldulensis* plot, showed greater soil erosion, compared with the other treatment. However, soil erosion in this plot also decreased during the succeeding years due to root mat formation, development of tree crown or surface coverage by the plant litter. Islam and Weil (2000) described that soil deterioration index improved by 6% in sites revegetated with fast-growing *Acacia*. Consequently, irrespective of the tree species adopted for erosion control plant, it might be possible to reduce erosion within a few years and with an improvement in the soil quality. In addition, fast-growing trees that are useful economically were compared with grasses for their erosion control potentials. Introduction of trees species are also promising economically. Thus it can be considered that, in terms of erosion control, grass species is better but tree species also can be utilized.

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