TRIOICS Vol. 1 (2/3): 113-129 Issued December, 1991

Improvement of Biological Productivity in Degraded Lands in Thailand II. Influences of Soil Temperature, Moisture, and Fertility on Plant Growth in the Takuapa Experimental Site

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Abstract On the sand and gravel tailings after tin mining in Takuapa, Phang-nga province, Thailand, *Eucalyptus camaldulensis* was planted mainly for rehabilitation of the degraded land, and cassava and pineapple were cultivated for demonstrating the possible way of agriculture. This work is a part of "Waste Land Project" (WLP), having been conducted in Thailand for six years.

Mulching among others was considered to be the best treatment for both trees and crops based on the following reasons, i) mulching lowered the maximum soil temperature in the hottest period, ii) it kept a good moisture condition throughout the year, iii) mulching materials could be utilized by plants as a source of nutrients as well as enhanced biological activity, and iv) they could be practiced easily, using weeds collectible *in situ*.

As far as rehabilitation of a barren land is mainly concerned, *Eucalyptus camaldulensis* combined with *Imperata* mulching proved to be most promising. On the other hand, in order to establish a practical approach to agriculture under the severely poor soil conditions encountered, further exertion is indispensable for the goal, i.e., a reasonable, at least, sustainable yield of cassava and pineapple.

Key Words: degraded land / *Eucalyptus camaldulensis* / soil conditions / Thailand / Waste Land Project

Concession of the tin mining is concentrated on the western coastal area of the peninsular Thailand, especially in high density in Phang-nga province. Total concession and abandoned areas in 1987 were 671 and 480 km^2, respectively, and covered altogether 0.22% of the total land area of Thailand (Tanpibal & Sahunalu, 1989). Most tin ores are found in alluvial deposits and mining operations by the two methods used, employ water for the mechanical separation of tin ore from the tin-bearing earth. This results in the deposit being separated into sand, clay, gravel, and their mixture in various composition. Among them, the sand depositional area occupies more than 80% of the total area (Tanpibal & Sahunalu, 1989). Vegetational cover after mining is quite sparse except for a few species, i.e., *Casuarina equisetifolia* trees on the sand deposit and *Imperata cylindrica* grassland on the clay deposit.

At a glance, there is nothing established on the land surface of the gravel tailings. Natural

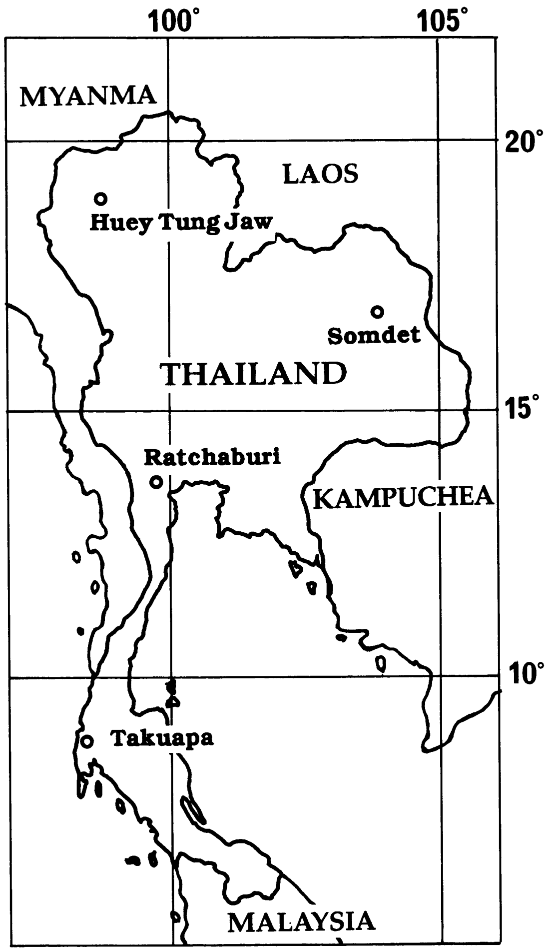

Fig. 1. Study sites.
Cited from Sakurai et al, 1989 (modefied).

regeneration of any plant species seems to be quite difficult, and therefore, utilization of this degraded land is far from the concern of farmers. In 1968, in order to restore the vegetational cover, the Department of Land Development established a Tin Mine Spoil Research Station. This station has conducted experiments concerning the utilization of tin mine tailings aiming at reforestation and agriculture, including fodder grass screening, cashew tree and cantaloupe trials with or without chemical fertilizer and city compost. Forest tree species trials have also been conducted (Tanpibal & Sahunalu, 1989). The major objective of the present work is to ensure a more intensive and efficient promotion of the various projects already set in motion.

STUDY SITE AND ANALYTICAL METHODS

Description of the Experimental Plots

Inside the Forestry Student's Training Station of Kasetsart University in Takuapa, Phang-nga province, situated 10 km west of Takuapa city and close to the Andaman Sea, a study site was established on the land after pump mining of more than twenty years (Fig. 1). After the reconnaissance in 1984, an experimental plot of 1.3 ha was demarcated in 1985, on a small fan-shaped sand and gravel tailing area, slightly sloping to the northwest (Fig. 2). Climatologically, Takuapa region belongs to Köppen's Am (Thailand Development Research

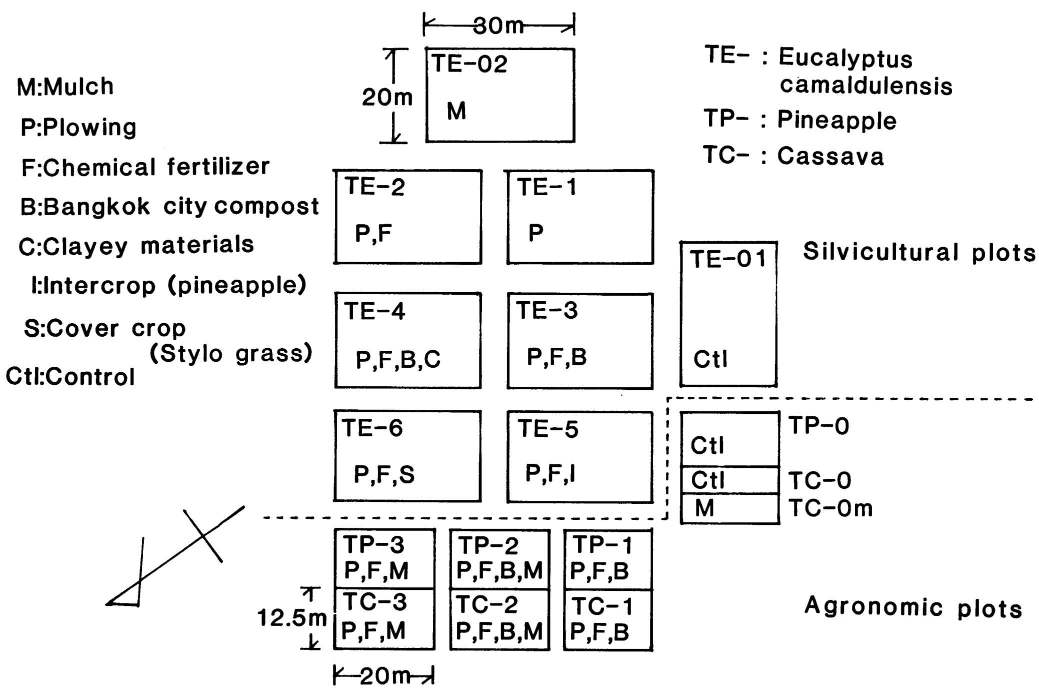

Fig. 2. Design of Takuapa experimental site.

Institute, 1987). The approximate altitude of the experimental site is 10 m above sea level.

Since soil profile description and physical properties in this experimental site have been shown elsewhere (Sakurai et al., 1989), a brief description of the site will be given below. In this site, gravel and sand layers appeared alternately throughout the soil profile, though at the very limited parts of the solum, thin clayey layers (less than 2 mm in thickness) were observed. Thus, these materials showed a very low water holding capacity and a hydraulic conductivity faster than 3×10^{-2} (cm/sec). Sahunalu & Anunsiriwat (1985) discussed the soil chemical and physical properties of seven different vegetational types of this station. They showed that the average clay content of gravel-sand tailings from three soil pits was 9%. However, in our experimental site, clay content was less than 2%.

Experimental Design

The layout of the experimental plots is shown in Fig. 2. Eight silvicultural plots and nine agronomic plots are summarized in Table 1 together with the treatments and their cost.

Silvicultural plots. *Eucalyptus camaldulensis* was selected out of several tree species based on the result obtained by Tanpibal & Sahunalu (1985), and planted in 2 m×2 m planting space, in May, 1985. TE-01 was designated as a control plot without any treatment before planting. TE-02 had been a control plot for 1 and half years after transplanting of the seedlings, until mulching treatment was initiated from December, 1986, using fresh grasses (*Imperata* sp.) collected from the abandoned local area near our experimental site. Mulching was conducted at the rate of 1 ton/plot (16.7 tons ha^{-1}), once a year, usually in December or January.

Plowing (TE-1 to TE-6) was carried out by hand hoe three times a year, usually in April, September, and November. Chemical fertilizer (15:15:15) was applied 3 times a year in TE-2

Table 1. Treatment and cost of each plot .

Silivicultural plots (*Eucalyptus camaldulensis*)

Plot	Area m2	Plowing	CF** (t/ha)	Compost (t/ha)	Mulch (t/ha)	Cost Bahts/ha	Max. Yield kg/ha	Max. Income Bahts/ha	Remarks
TE-01	600	—	—	—	—	—			
TE-02	do.	—	—	—	16.7	16,700			1.00 $ = 25.5 Bahts
TE-1	do.	May	—	—	—	—			
TE-2	do.	do.	1.67	—	—	10,020			
TE-3	do.	do.	do.	12.5	—	28,770			
TE-4	do.	do.	do.	do.	—	28,770			Clayey material dressing
TE-5	do.	do.	do.	—	—	—	2,008	3,020*	Pineapple intercroping
TE-6	do.	do.	do.	—	—	—			Cover plant (*Stylosanthes hamata*)

Agronomic plots (TC:Cassava, TP:Pineapple)

Plot	Area m2	Plowing	CF** (t/ha)	Compost (t/ha)	Mulch (t/ha)	Cost Bahts/ha	Max. Yield kg/ha	Max. Income Bahts/ha	Remarks
TC-0	125	—	—	—	—	—	—	—	
TC-0m	do.	—	—	—	36	36,000	2,350	1,495*	
TC-1	250	May	4	24	—	60,000	17,110	10,882*	
TC-2	do.	do.	4	24	36	96,000	26,420	16,803*	
TC-3	do.	do.	4	—	36	60,000	11,910	7,575*	
TP-0	do.	do.	—	—	—	—	320	481*	
TP-1	do.	do.	4	24	—	60,000	10,724	16,129*	
TP-2	do.	do.	4	24	36	96,000	23,716	35,669*	
TP-3	do.	do.	4	—	36	60,000	16,180	24,335*	

*: Average farm prices from 1980 to 1989 were used for calculation, 1.504 Bahts/kg for pineapple, and 0.636 Bahts/kg for cassava (according to Office of Agricultural Economics, 1990).

**: Chemical Fertilizer.

—: Not applied.

to TE-6; 30 kg/plot in April, 35 kg/plot in September and 35 kg/plot in November, totalling 100 kg/plot (1.67 tons ha^{-1}). City compost (Bangkok, No.1) of total 750 kg/plot (12.5 tons ha^{-1}) a year was applied in TE-3 and TE-4; 300 kg/plot in April, 200 kg/plot in September, and 250 kg/plot in November. Both chemical fertilizer and city compost were applied by broadcasting and mixed with the surface soil (approximately up to 10 cm depth) by hand hoe. However, both chemical fertilizer and city compost were applied only at the beginning of the experiment in 1 m×1 m square around the planting spot for TE-2, TE-3, TE-5, TE-6, on one hand, but in a different way for TE-4.

Original land preparation of TE-4 was as follows; 0.125 m^3 of clayey materials was mixed thoroughly with 5 kg of compost and 0.667 kg of chemical fertilizer, and transferred into a box (50×50×50 cm in size). After the box was removed from the planting spot, the land was leveled and seedlings transplanted. Accumulated clayey materials resulting from mining concession were collected close to the experimental site. These had 43% of solid ratio and 2.67 of true density, i.e., 0.125 m^3 of them corresponded to 143 kg of oven-dried soil.

Furthermore, we had some special treatments together with Eucalypt plantation in TE-5 and TE-6, aimed at agroforestry. In TE-5, pineapple (*Ananas comosus*) was planted as intercrop, while in TE-6, covering plants were grown. Leguminous species, *Stylo* grass (*Stylosanthes hamata*) was used to cover the land surface and to improve the degraded condition because of its nitrogen fixing ability (Tanpibal & Sakurai, in prep.).

Agronomic plots. Cassava (*Manihot esculenta*) and pineapple were grown in the agronomic plots, and expressed as TC and TP, combined with the numeral representing the treatment applied (see Fig. 2 and Table 1).

Planting space and population density for cassava were 0.5 m×0.5 m and 35,520 plants ha^{-1}, respectively, which seemed to be a little bit too dense, compared with the experiment conducted by El-sharkawy & Cook (1987). It was, however, equivalent to that adopted in the commercial plantation. Cassava was planted at the onset of rainy season (late April), every year and harvested on late January, i.e., growth period was nine months.

On the other hand, planting space and population density for pineapple were 0.5 m×0.3 m with 1 m interval between rows, and 38,400 plants ha^{-1}, respectively. The value of plant density seem to be moderate in reference to figures appearing elsewhere (Bartholomew & Kadzimin, 1977). Pineapple was firstly planted on April, 1985 and harvested on Oct., 1986, and secondly planted on April, 1987 and harvested on Oct., 1988. It took eighteen months to collect fruits. Flower inducer (ETHREL, commercial products name in Thailand) was applied on April and May, 1986 for first crop, and May, 1988 for the next. Without it, yield would have been very poor under the prevailing conditions.

Both of these are important cash crops in Thailand. According to Agricultural Statistics of Thailand (Office of Agricultural Economics, 1989), cassava has been harvested mainly in 42 provinces out of 73. This crop is said to occupy 1.62 million ha and the third most cultivated crop in the whole of Thailand, following paddy (10.35 million ha) and maize (1.84 million ha). On the other hand, pineapple is harvested in 10 provinces mainly in the central plain and its total area in Thailand is said to be 0.071 million ha. Although dominant cash crops in the Southern Thailand are perennial tree species such as cashew, rubber, oil palm, coffee, and durian (Thailand Development Research Institute, 1987), they need several years before harvest. Cassava and pineapple can be harvested within a relatively short period, thus ensuring rapid production and spread. Demonstration of the cultivation of these crops on the gravel tailings was an important purpose of our work.

For TC-1 to TC-3 and TP-1 to TP-3, chemical fertilizer (15:15:15) was applied three times a year; 30 kg/plot in April, 35 kg/plot in September and 35 kg/plot in November, totalling 100 kg/plot (4 tons ha^{-1}). City compost (Bangkok compost No.1) of 600 kg/plot (24 tons ha^{-1}) a year was applied in TC-1, TC-2, TP-1, and TP-2, usually 200 kg/plot in April, 200 kg/plot in September, and 200 kg/plot in November. Both chemical fertilizer and city compost were applied by broadcasting and mixed with the surface soil (approximately up to 10 cm depth) by hand hoe.

Mulching by fresh imperata grass carried out in TC-0m, TC-2, TC-3, TP-2, and TP-3 was at the rate of 36 fresh tons ha^{-1} $year^{-1}$ (250 kg/plot for TC-0m, and 500 kg/plot for the others).

Analytical methods. All chemical analyses presented in this chapter were conducted in Department of Soils, Faculty of Agriculture, Kasetsart University, Thailand. Analytical items (and their abbreviation in parentheses) and methods are as follows: pH in water (pHw) and/or 1N-KCl (pHK), 1:5 of soil:solution ratio; electric conductivity (EC), 1:5 of soil to water ratio; organic matter (OM), Walkley-Black method; total nitrogen (T-N), wet digestion and distillation; available nitrogen (Av.N), distillation by N-KCl extract; available phosphorus (Av. P), Bray No.2 method; exchangeable cations (Ex. Ca, Ex. Mg, Ex. K, and Ex. Na), N-ammonium acetate (pH 7) extraction; cation exchange capacity (CEC), N-ammonium acetate (pH 7) method; acidity (Exchangeable hydrogen and aluminum, Ex. H and Ex. Al), N-KCl extraction.

RESULTS AND DISCUSSION

Precipitation, Air and Soil Temperature

During June 1985 to January 1990, daily rainfall as well as maximum and minimum temperature were recorded at the experimental site. In Fig. 3, monthly precipitation and average maximum and minimum temperatures are depicted. Total precipitation in 1986 amounted to 4,721 mm and the average of 4 years was 3,112 mm. Maximum temperature ranged from 30 to 48°C and minimum temperature ranged from 17 to 28°C. Since the thermometer was set about 30 cm above the ground surface, monthly mean maximum temperature exceeded 45°C

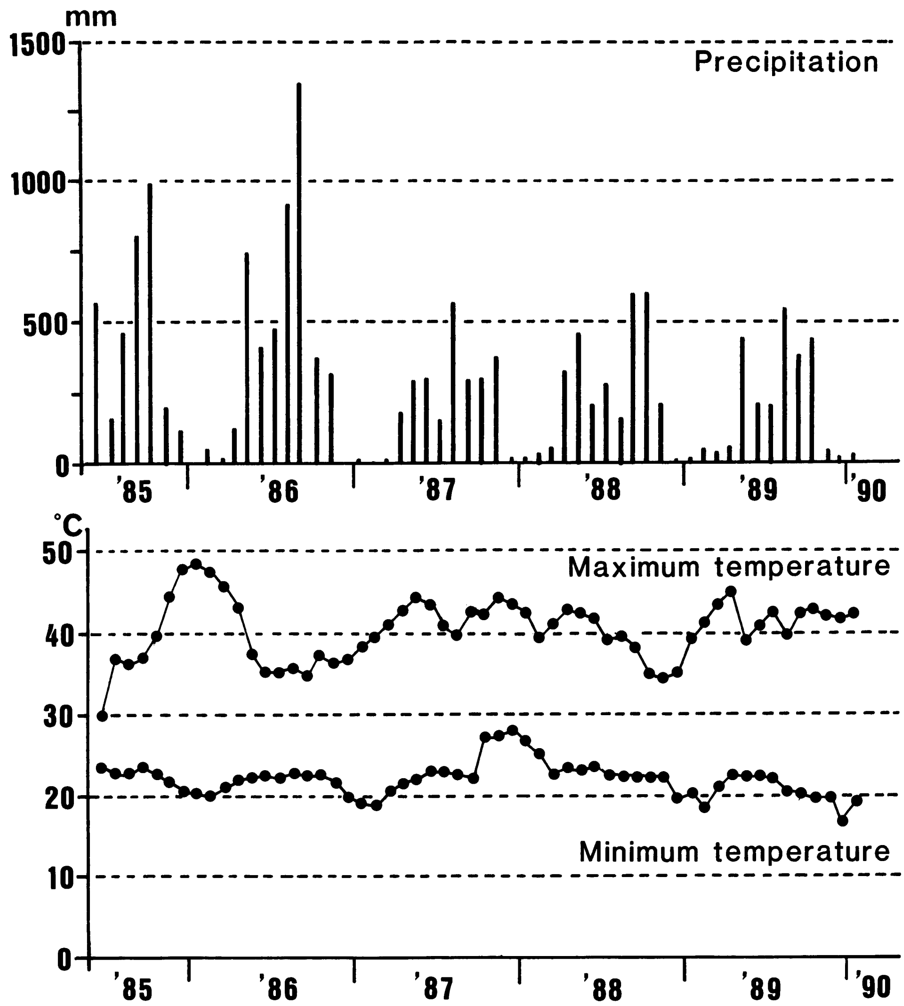

Fig. 3. Monthly precipitation and average maximum and minimum temperatures from October 1985 to January 1990.

in several months. Temperature in summer was not always the highest within a year due to frequent and heavy rainfall. The meteological data indicated a perhumid condition in the rainy season, but an excessively hot and dry condition in the dry season. Growth of trees and crops planted might suffer from both of these extreme conditions.

Total biomass of planted trees have after 4 years in each plot and the amount (tons of dry matter ha^{-1}) was in such a sequence (Kanzaki *et al.*, in prep.);

TE-4 >>TE-2 >TE-3 >TE-5 >TE-6 >TE-02 >TE-01 >TE-1

44.5 22.2 22.0 19.4 14.7 11.2 1.5 1.4

To investigate the effects of treatments applied on soil temperature, thermometers were set in four plots (control, TE-02, TE-4, and TE-6) at four depths (ground surface (0 cm), 5, 10, and 30 cm). Some of the features in these plots are as follows: i) control plot was on the bare land with little grass around, ii) TE-02 was covered with mulching materials, approximately 10 mm in thickness, and the tree growth in TE-02 was less conspicuous than that in TE-4 and TE-6, iii) in TE-6, tree growth was intermediate between TE-02 and TE-4, and growth of the *Stylo* grass was too poor to cover the soil surface, and iv) TE-4 shows maximum growth of the planted trees, which would possibly supply a significant shading to the soil surface. Measurements were carried out every day at 12 o'clock during October 1988 to January 1990. Fig. 3 shows the monthly mean soil temperature in control and TE-02 , representing the highest and the lowest soil temperatures at the surface and 5 cm-depth. Surface temperature in the dry season often attained to 50°C in the control plot, whereas, in TE-02, it was not more than 40°C. Furthermore, soil temperature at 5 cm in TE-02 was not greatly different from that at 10 cm and 30 cm.

Lal (1974) demonstrated the effect of rice straw mulching (4 tons ha^{-1}) in Nigeria on lowering the temperature of soils at various depths, i.e., 5, 10, 20 cm. He found that, at the initial growing stage of maize, temperature differed as much as 8°C between mulched and unmulched plots at the 5 cm-depth. Soil temperature fluctuation observed in TE-02 was the smallest of all, and therefore, mulching had kept a good temperature condition for roots throughout the year.

In Fig. 4, soil temperatures at 5 cm depth in every four plots are shown, since fine tree roots for sucking up water and nutrients actively concentrated at this depth as well as 10cm. As described already, TE-02 (mulching) showed lowest and TE-01 (control) showed highest temperature. On the other hand, lower soil temperature of TE-4 (exhibiting the best tree growth) as compared to TE-6 (with sparsely grown cover grass) was observed. This fact indicates that in order to reduce the solar radiation to the surface soil, tree shading would be slightly more effective than sparsely grown cover plants.

Soil Moisture

Soil moisture content was monitored for more than 5 years using gypsum block buried at the depth of 20, 40, and 60 cm in 5 replications. Measurement was conducted on TE-1, TE-02, TE-4, TE-6, TC-1 and TC-2. Fig. 5 shows the example of soil moisture content in silvicultural plot at the depth of 20 cm in TE-02 (mulching), TE-1 (no treatment except plowing), and TE-4 (under the biggest canopy of *E. camaldulensis*, but at the different place where clayey materials were dressed) from October 1988 to September 1989. Vertical axis in Fig. 5 represents the resistance value of the gypsum blocks expressed in kilo-ohm. According to the laboratory measurement, resistance values of 2.8, 4.6, 20, and 2000 are nearly equivalent

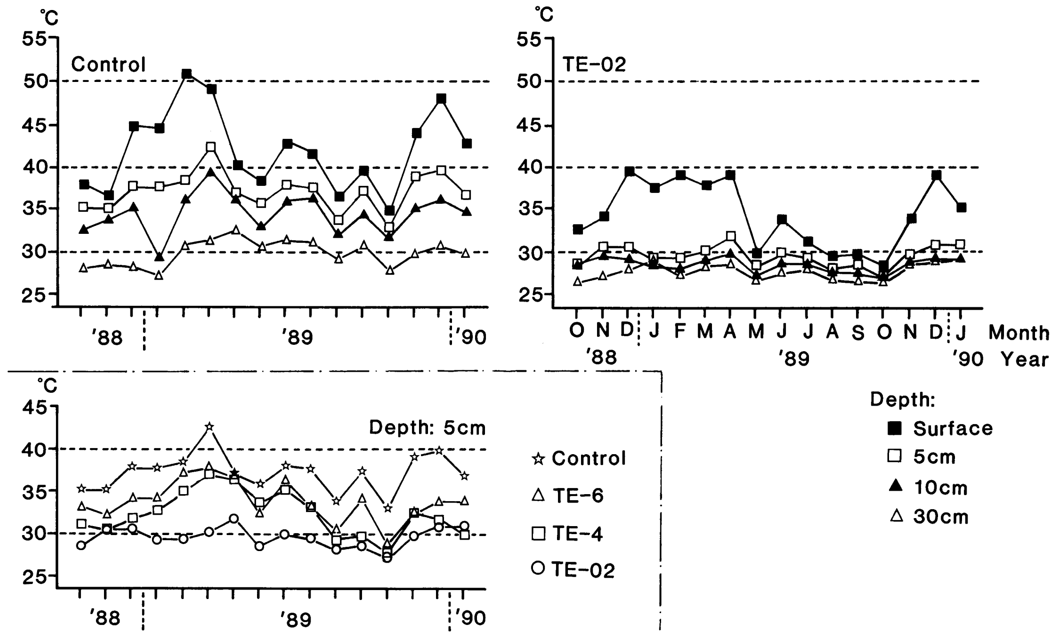

Fig. 4. Monthly mean soil temperature (Oct. 1985 to Jan. 1990). Upper: at different depths in control and TE-02. Lower: at the depth of 5 cm in four plots.

to pF values of 1.0, 2.0, 3.0, 4.0 for this soil, respectively. Thus, resistance value higher than 2000 may correspond to the critical moisture level for plant growth.

During rainy season, i.e., October to December, 1988 and June to September, 1989, soil moisture contents were kept below the critical level for all plots, while, they became too dry to maintain the appropriate condition for tree growth of TE-1 and TE-4, during January to May, 1989. On the other hand, in TE-02, soil moisture level was always below pF 3.0 at the depth of 20 cm throughout the year. In the previous section, we confirmed the effectiveness of mulching in reducing soil temperature even in the dry season in TE-02, which would be brought by the higher soil moisture content.

Lal (1974) explained that mulching at the maize field decreased evaporation losses only when the soil was at the first stage of the drying cycle. However, in this region, ground water level exists within 2 m even in dry season, and therefore, if mulching protect against the severe evaporation, water supply from the lower horizons would not be hindered. Thus, it can be concluded that mulching is indispensable to maintainance of soil moisture.

On the other hand, TE-1 showed much poorer tree growth but maintained better moisture condition than TE-4. This result can be attributed to the difference in the amount of evapotranspiration of Eucalypt. Bigger trees need more water in soils and releases more by evapotranspiration, which would surpass direct evaporation from soil.

In Fig. 6, soil moisture content in TC-1 (no mulching) and TC-2 (mulching) is depicted. It is quite clear that mulching plot (TC-2) could keep more water than non-mulching plot (TC-1). Good moisture condition in soils will give a good yield of cassava, as will be described later.

Gypsum blocks buried in the deeper horizon (60 cm-depth) after 2 years were damaged to some extent by the weight of the overlying soil materials, however it still maintained a

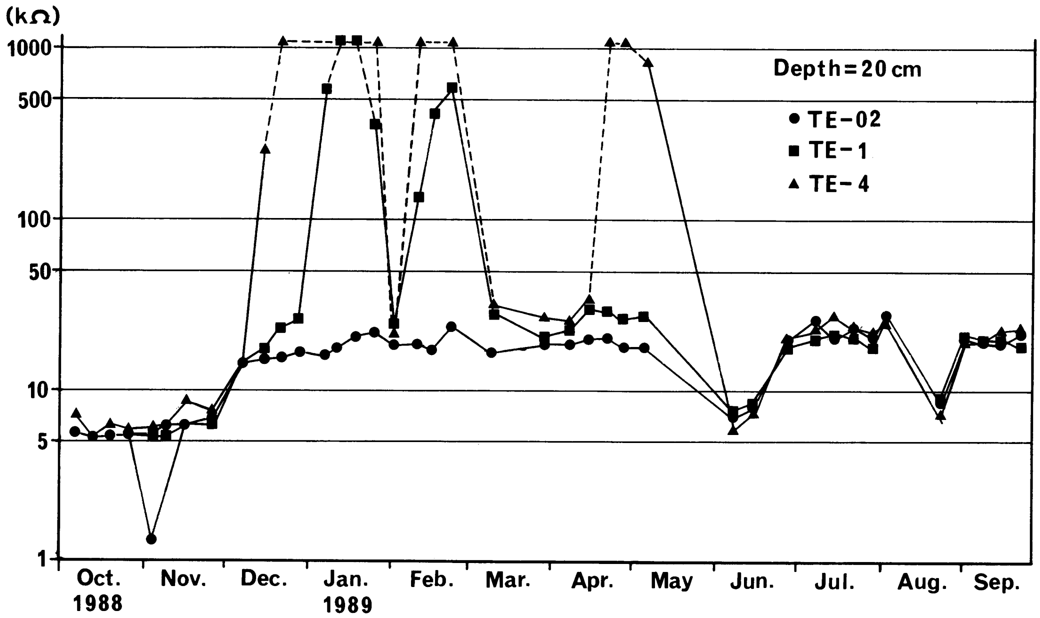

Fig. 5 Soil moisture condition monitored by gypsum blocks (1). Silvicultural plot.

reasonable quality for detection of moisture condition.

Soil Moisture Tension Measured in situ

Moisture contents of subsurface and/or surface horizons have been measured gravimetrically, and monitored by gypsum blocks. However, the level of effective water still remained unknown. Thus, in 1989, pF value in situ was evaluated at every experimental site, using tensiometer buried at a depth of 20, 40, 60 and 80 cm. Table 2 shows these results.

Reflecting the heavy rain encountered every day during measurement, pF value in Takuapa Experimental Site ranged from 1.0 to 2.0 and they were quite low compared with the other sites. Generally, lower horizons showed higher pF values representing lower moisture content. It can be inferred that lower horizons were not quickly affected by the daily rainfall, and therefore, showed different tendency from the upper horizons.

Table 2. Changes in pF condition measured *in situ.*

Plot	Days after setting	Depth (cm) 20	40	60	80
TE-02	1	1.29	1.20	1.37	1.57
	2	1.23	1.23	1.46	1.39
	3	1.03	1.55	1.73	1.41
	4	1.69	1.71	1.87	1.88
	5	1.63	1.26	-	1.83
TE-1	1	1.09	1.47	1.51	1.65
	2	-	1.54	1.57	1.65
	3	-	1.23	-	1.49
	4	-	1.81	-	1.59
	5	-	1.67	1.84	1.93
TE-4	1	1.32	1.32	1.29	1.51
	2	1.49	1.54	1.35	1.72
	3	1.58	1.37	1.27	1.49
	4	1.73	1.79	1.71	1.42
	5	1.63	1.85	1.69	1.91

-: not measured

Changes in Soil Chemical Characteristics

Sample collection for analysis was conducted at least twice a year, usually, before and after soil treatment on every year. It was true that analytical value for the samples collected just after compost and chemical fertilizer

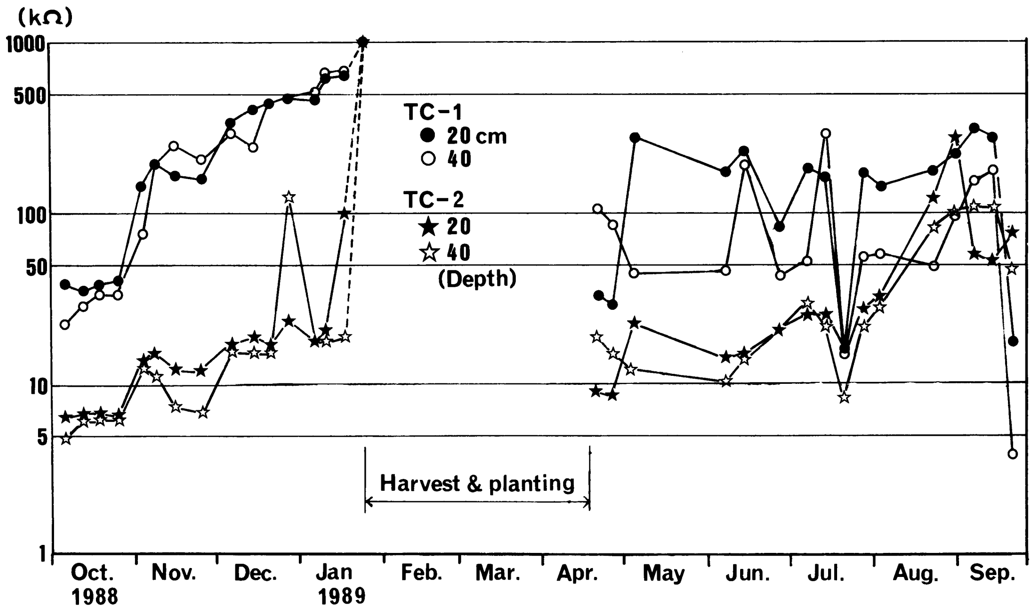

Fig. 6. Soil moisture condition monitored by gypsum blocks (2). Agronomic plot.

application showed a sharp increase in organic matter content for the former and nitrogen, phosphate, and potassium content for the latter, though the observed increase was not persistent. Analytical results at the initial condition (average value) and after 48 months experiment are summarized in Table 3. Some of the outstanding feature will be described below.

Silvicultural plots. The value of pHw was around 5.0 in the surface soil, and ranged from 4.5 to 5.0 in the subsurface. Application of compost increased pH values to beyond 6.0 and 7.0 for surface and subsurface soils, respectively. Fluctuation in pHw was significant, especially after application of compost and/or chemical fertilizer. The former increased the pHw, and the latter decreased it.

Originally, organic matter content was quite low. However, at the end of the 4-year-treatment, it increased in the surface soils almost on every plot. In TE-02, mulching materials (*Imperata* grass) was not likely to be left in the soil more abundantly than the compost (TE-3 and TE-4) as a source of organic matter. In the field observation, compost was not decomposed, but existed as discrete particles in soils for a long time. On the other hand, in TE-02, soil color itself changed and a lot of macro fauna (mainly earthworm) were found in surface 10 cm. Furthermore, though this was not reflected on the analytical result of OM, mulching seemed quite effective to increase biological activity in soils.

In addition, total nitrogen (T-N), available phosphate (Av. P), sum of exchangeable bases (Ex. B) increased significantly in TE-3 and TE-4, where both compost and chemical fertilizer were applied. On the other hand, without application of chemical fertilizer, there was no increase in Av.P in TE-02.

Soils in Takuapa showed a quite low soil fertility. Above all, OM content is extremely low. In this sense, only OM application like compost and mulching could change the soil fertility. Among them, mulching was most promising to enhance the biological activity, which is one of the most important factors to make a good soil (Syers & Springett, 1984).

Agronomic plots. A similar tendency was recognized as in the silvicultural plots. Since

Table 3. Soil fertility at the initial condition (average value) and after 48 months.

Silvicultural plots

		Initial condition	*Eucalyptus camaldulensis* (after 48 months) TE-01	TE-02	TE-1	TE-2	TE-3	TE-4	TE-5	TE-6
pH	Upper	5.2	5.1	5.5	5.2	4.8	6.7	6.2	4.8	4.9
	Lower	5.1	5.2	5.4	5.2	4.8	6.9	4.9	5.1	4.6
Organic	Upper	0.09	0.3	0.6	0.1	0.5	1.7	1.0	0.2	0.4
matter(%)	Lower	0.03	0.1	0.1	0.1	0.2	0.4	0.2	0.1	0.1
T-N	Upper	67	123	210	70	158	770	408	70	158
(ppm)	Lower	18	35	35	175	70	158	70	35	35
Av.N	Upper	14	7	14	7	14	28	21	14	14
(ppm)	Lower	14	7	7	14	7	0	14	0	7
Av.P	Upper	4	2	4	2	36	382	193	23	49
(ppm)	Lower	3	1	1	2	26	52	16	12	20
Ex.K	Upper	10	30	60	25	25	40	30	25	30
(ppm)	Lower	10	20	20	20	20	25	20	140	20
Ex.B	Upper	0.24	0.38	0.49	0.26	0.22	4.44	3.84	0.35	0.43
(meq/100g)	Lower	0.24	0.31	0.26	0.29	0.21	1.44	0.51	0.85	0.22

Agronomic plots (cassava and pineapple)

			Cassava					Pineapple			
		Initial	After 57 months					After 30 months			
		condition	TC-0	TC-0m	TC-1	TC-2	TC-3	TP-0	TP-1	TP-2	TP-3
pH	Upper	5.2	6.3	5.4	7.1	7.0	4.8	4.8	7.2	7.0	4.5
	Lower	5.1	6.3	6.3	7.0	6.9	4.9	5.3	6.8	6.1	4.9
Organic	Upper	0.09	0.2	1.0	2.7	2.2	1.3	0.3	1.4	1.9	0.4
matter(%)	Lower	0.03	0.1	0.1	0.1	1.6	0.3	0.0	0.1	0.1	0.1
T-N	Upper	67	100	400	1300	1000	200	158	630	823	140
(ppm)	Lower	18	100	100	100	200	40	18	35	57	70
Av.N	Upper	14	7	14	14	21	14	14	14	14	7
(ppm)	Lower	14	14	14	14	21	14	28	14	0	7
Av.P	Upper	4	3	3	1213	750	107	2	522	446	149
(ppm)	Lower	3	2	2	24	119	49	2	9	11	32
Ex.K	Upper	10	20	20	30	30	20	10	30	30	20
(ppm)	Lower	10	20	10	10	10	20	20	20	20	10
Ex.B	Upper	0.24	0.34	0.46	4.47	3.82	0.47	0.47	5.07	7.35	0.33
(meq/100g)	Lower	0.24	0.37	0.31	0.59	0.94	0.60	0.14	0.38	0.36	0.25

the application rate of compost and chemical fertilizer in the agronomic plots was higher than in the silvicultural plots, difference between fertilized and non-fertilized plots was greater.

Every specific value on soil fertility was higher in mulching plots (TC-1, -2, TP-1, -2) than in non-mulching (TC-1, TP-1), and non-fertilized plots (TC-0, TP-0). In TC-0m, mulching treatment was applied in addition to TC-0 (plowing only), and consequently, higher organic matter and total nitrogen content were observed in TC-0m than in TC-0. As stated before, in mulching plot under *Eucalyptus*, we could find abundant earthworms. However, there was no proof of earthworm activity under mulching in TE-0m probably due to the yearly plowings in preparation for new crops. Tree plantation is more favorable way of management than intensive agriculture to improve biological activity under such an extremely poor soil condition.

Among two agronomic plots, the amount of OM, T-N, and Av. P in cassava plots was more than that in pineapple plots, whereas, the other properties fluctuated in a similar manner with each other, and also to the same degree. The reason for this phenomenon would be a subject to study furthermore.

Yield of Cassava and Pineapple

In order to exemplify the possibility of agriculture on the gravel tailings after tin mining, cassava and pineapple were cultivated in Takuapa. Yield of cassava is summarized in Table 4. The highest yield was always obtained in TC-2, where mulching, city compost, and chemical fertilizer were applied. When chemical fertilizer was applied, mulching (TC-3) and city compost (TC-1) gave almost same effect on the cassava yield for 4 years. On the contrary, little products could be collected from the control plot, TC-0. However, with only mulching, (TC-0m), the yield went up to approximately to one-fourth that of TC-3. These data indicated the effectiveness of mulching.

It is quite obvious that luxurious treatment in TC-2 gave the highest yield even under a poor soil condition both in chemical and physical properties. However, considering the economical aspect, intensive treatments conducted here were far beyond sustainable. Mulching materials such as *Imperata* grass can be collected easily from the local abandoned area, and therefore, promising way of approach here. Furthermore, if possible, application of chemical fertilizer at the same time will assure a reasonable produce of cassava.

In Tables 4 and 5, total biomass of cassava and pineapple is shown. Yield of cassava is represented in fresh weight basis only in 1986. Judging from another four years' data and calculating into oven-dried basis, approximately 25% of fresh weight would be equivalent to the dry weight. Accordingly, cassava dry yield of 1986 would amount to the mean of those of 1988 and 1987.

According to the Office of Agricultural Economics (1989), average cassava yield in Thailand from 1980 to 1989 was 14.96 t fresh root ha^{-1}. Verapattananirund *et al.* (1988) reported the yield of 16.6 t fresh root ha^{-1} on the sandy soils in North-east Thailand, using a traditional farmers' practice of plow-harrow before planting and three hand-weeding operations during the initial stages of cassava development. Compared with their result, 21.2 t fresh root yield ha^{-1} of TC-2 in 1986 showed the possibility that careful management could produce enough amounts of cassava even in far more infertile soil after mining at Takuapa in Southern Thailand. El-Sharkawy & Cock (1987) showed the yield of 57 t fresh root ha^{-1} in Colombia, using high yielding variety, CM 507-37. Introduction of a high yielding variety may enable commercial management of this crop.

Average yield of pineapple in Thailand from 1980 to 1989 was 24.17 *fresh* tons ha^{-1} (Office of Agricultural Economics, 1989), whereas, Sanchez (1976) reported the yield of 12.5 *dry* tons ha^{-1}. Even at the luxurious plot (TP-2), its highest yield in 1988 was 3.06 dry tons and 23.72 fresh tons ha^{-1}. It was considered as comparable to the standard value in Thailand, but not high at all considering the intensive treatments. Furthermore, after the first harvest, we could not do any more harvesting. Commercial plantation in more profitable condition found in the central plain of Thailand could harvest at least 3 crops in 3 years. Considering these situation, successful management of pineapple on the gravel tailings need more effort and research activity.

Total biomass of pineapple in TP-2 was highest, 13.1 tons ha^{-1} in 1988, and 50% higher than that of cassava (TC-2), 9.58 tons ha^{-1} in 1988. Cropping periods of one and half year for pineapple and eight months for cassava, might be a reason for it. This relationship was true

Table 4. Biomass of cassava from 1985 to 1990.

Plot Part	Jan.'86	Feb.'87	Jan.'88	Jan.'89	Jan.'90
TC-0					
Leaf	0	0	0	0	0
Stem	0	0	0	0.004	0
Tuber	0	0	0	0	0
Stick	0	0	0	0.042	0
Total	0	0	0	0.046	0
TC-0m					
Leaf	-	0.002	0.024	0.007	0.008
Stem	-	0.080	0.232	0.215	0.302
Tuber	-	0.417	0.960	0.976	0.654
Stick	-	0.259	0.252	0.333	0.566
Total	-	0.758	1.468	1.531	1.530
TC-1					
Leaf	0.080 (0.017)	0.056	0.344	0.079	0.060
Stem	8.332 (2.600)	0.364	1.368	2.081	1.192
Tuber	11.044 (3.069)	0.720	2.520	4.756	2.602
Stick	-	0.468	0.696	0.811	0.716
Total	19.456	1.608	4.928	7.726	4.570
TC-2					
Leaf	0.068 (0.014)	0.044	0.204	0.020	0.036
Stem	10.456 (3.262)	0.608	3.076	1.936	1.626
Tuber	21.208 (5.896)	3.148	5.588	7.344	4.857
Stick	-	0.700	0.716	0.803	1.105
Total	31.732	4.500	9.584	10.104	7.624
TC-3					
Leaf	0.056 (0.012)	0.020	0.124	0.047	0.020
Stem	6.776 (2.114)	0.280	1.380	0.882	0.882
Tuber	8.832 (2.455)	1.688	3.312	3.281	3.200
Stick	-	0.432	0.580	0.645	0.684
Total	15.664	2.420	5.396	4.855	4.786

(tons/ha, oven-dried basis)
-: no data
Figures in parentheses represent the calculated values into oven-dried weight

for the other plots with the same soil treatments, namely, between TC-1 and TP-1, TC-3 and TP-3.

Combination of mulching and chemical fertilizer (TP-3) produced approximately 50% more biomass of pineapple (as well as crop yield) than that of compost and chemical fertilizer (TP-1). This was not true for cassava, namely, these two treatments seemed to be equivalent in yield. Response to the treatments between pineapple and cassava can be explained by their root distribution. Pineapple roots are concentrated on the surface soil near the mulching materials, whereas, cassava root develops more deeper in the solum. Pineapple roots, therefore, could receive more profitable effect from mulching since the prosperous roots are concentrated just below mulching. Another possible cause may be that cassava roots suffer from the over-wetting condition in the rainy season, which often spoils the quality of root. In this sense, mulching treatment as water holding material would not contribute more than as ion exchanger, especially for cassava.

Table 5. Biomass of pineapple from 1986 to 1988.

Plot Part	Oct.'86		Oct.'88	
TP-0				
Fruit	0	0.080*	0.052	0.320*
Stalk	0		0.016	
Crown	0		0.084	
Leaf+stem	-		1.028	
Root	-		0.536	
Total	0		1.716	
TP-1				
Fruit	0.408	2.808*	1.380	10.724*
Stalk	0.396		0.164	
Crown	0.156		0.640	
Leaf+stem	-		2.876	
Root	-		0.992	
Total	0.960		6.052	
TP-2				
Fruit	1.428	15.357*	3.056	23.716*
Stalk	0.944		0.272	
Crown	0.596		0.780	
Leaf+stem	-		7.668	
Root	-		1.164	
Total	2.968		13.140	
TP-3				
Fruit	0.748	5.158*	1.876	16.180*
Stalk	0.152		0.180	
Crown	0.272		0.736	
Leaf+stem	-		4.792	
Root	-		1.812	
Total	1.172		9.396	
TE-5				
Fruit	0.072	0.628*	0.248	2.008*
Stalk	0.044		0.020	
Crown	0.028		0.088	
Leaf+stem	-		0.608	
Root	-		0.664	
Total	0.144		1.628	

(tons/ha, oven-dried basis)
-: no data *: fresh weight

Chlorophyll Content

Chlorophyll and nitrogen content of leaves has been studied especially for the appropriate fertilization to rice plant (Youn & Ota, 1973). Unfortunately, adaptability of this relationship to cassava has not been clarified yet, and upon this, we tried to evaluate chlorophyll content of cassava leaves using chlorophyll meter (SPAD 501).

Chlorophyll meter, SPAD 501, was devised in 1983 by Soil and Plant Analyzer Development. Some researchers have exemplified the linear relationship between reading of the meter and nitrogen content in leaves of rice plant (Tyubachi *et al.* 1986; Kitagawa *et al.* 1987). In addition, both have been found to be higher in the vegetative stage than in the productive stage (Kitagawa *et al*, 1987). Furthermore, the linear relationship was confirmed between readings and the actual content of chlorophyll (M. Ueno, 1990), where regression equation was different among cultivars of rice plant.

Measurement was conducted for seemingly active cassava leaves (24 weeks after planting) in 1985, 1987, 1988, and 1989. Since chlorophyll content was reported to be fluctuated with the growing stage of rice plant, growth and development of cassava will be reviewed briefly according to El-Sharkawy & Cook (1987); During the first few weeks of crop establishment, the plants form a fibrous root system, mainly in the upper layer (1 m) of soil. About 2 to 3 months after planting, some of the fibrous roots (from 5-15 roots per plant) start to expand rapidly, forming storage roots for starch. The formation of leaves in cassava has preference for available assimilates over storage roots in the first 3 months of growth. However, after this period, cassava continues to form new leaves concurrently with storage root filling. The leaf area index (LAI), leaf area per ground unit area, increases in the first 3 to 6 months and then declines gradually as the older leaves in the lower strata of the canopy fall.

Taking this into consideration, the ages of the leaves when examined (24 weeks) were generally at the maximum LAI stage when root filling has already started. Thus, chlorophyll

Table 6. Result of Duncan's multiple range test for the readings of chlorophyll meter of cassava leaves. Upper: plot name. Lower: mean values of the readings of chlorophyll meter.

Year/age (Replication)	Plot name and Readings of chlorophyll meter				
1985/24w	TC-0	TC-3	TC-1	TC-2	
(n=70)	21.2^{a}	22.7^{b}	35.2^{c}	37.5^{d}	
1987/24w	TC-0	TC-0m	TC-3	TC-2	TC-1
(n=55)	24.9^{a}	27.4^{b}	42.3^{c}	47.1^{d}	49.9^{e}
1988/24w	TC-0	TC-0m	TC-1	TC-3	TC-2
(n=20)	19.8^{a}	26.4^{b}	33.2^{c}	33.2^{c}	36.2^{d}
1989/24w	TC-0	TC-0m	TC-3	TC-1	TC-2
(n=20)	25.5^{a}	30.6^{b}	34.1^{c}	35.8^{c}	41.9^{d}

content of leaves would be reflected on the yield and biomass. Results of measurement were summarized in Table 6, together with the result of Duncan's new multiple range test. Simple correlation analysis during 1987 to 1989 was conducted, excluding the data in 1985 because no data were available on crop yield and total biomass on oven-dried basis. Correlation coefficients of 0.75 and 0.67 were obtained between readings of chlorophyll meter and total biomass and also between readings and crop yield, respectively. These values are not significantly high, but could be used as an index to predict the yield. Research activity including the examination on a optimal timing of measurement merit further attention since this measurement is very simple and considered to be valuable for practical manipulation of tropical crops through an appropriate and direct countermeasure.

Economical Aspect

Economical aspect is very important even for sustainable agriculture. In that sense, intensive treatments are equivalent to the money consuming practice. In Table 1, treatment cost, maximum yield during this experiment, and calculated maximum income using average farm price from 1980 to 1989 are included. For.cassava, farm price fluctuated significantly within these 10 years, from 0.40 to 0.89 Bahts/kg (Office of Agricultural Economics, 1990). That is also true for pineapple, i.e., 0.91 to 1.98 Bahts/kg. Taking these values into consideration, the calculated maximum income is much less than the investment for cassava. However, pineapple cultivation using mulching and chemical fertilizer (TP-3) would be more promising, if farmers can collect mulching materials by themselves. Mulching materials such as *Imperata* grass can be collected easily from the local abandoned area. At the same time, this practice can be considered as weeding, which will supply further land for agriculture. Besides, in our experiment, the amount of mulching materials was too much to apply routinely (36 tons ha^{-1}). This amounted to 9 times greater than that adopted by Lal (1974), who used 4 tons ha^{-1} of rice straw for mulching. Thus, quantitative evaluation of the amount of mulching on crop yield should be further studied. It will make it possible to think out a more profitable way to agriculture in Takuapa.

ACKNOWLEDGMENTS The authors are grateful to the organizers of the agroforestry research project, of which the present research was a part, and to the Ministry of Education, Science and Culture of Japan for funding (59041056, 60041063, 62041088, 63041110). They wish to express their most sincere thanks to all the members of Waste Land Project

(WLP, appeared on the running title) who cooperated with them throughout the project period, particularly to Dr. M. Kanzaki, Osaka City University, Japan, and Drs. P. Sahunalu and P. Danmanonda, Kasetsart University, Thailand.

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Received June 20, 1991
Accepted Oct. 13, 1991

桜井克年，B. Prachaiyo，T Attanandana，V. Tanpibal，荒木　茂，長縄貴彦，岩坪五郎，依田恭二　タイの土壌劣化地における生物生産力の回復　II.　タクアパ実験地における植物の成長に対する土壌温度，湿度，肥沃度の影響

タイの半島部，特にパンガ県 (Phang-nga Province) にはスズ鉱山が多い。スズ鉱石を水で選別した跡地には，粒径によって選別された粘土，砂，礫の放棄地が残る。放棄地での天然更新は大変困難であり，人為的な植生回復の試みがなされている。そこで本研究は「放棄地計画，Waste Land Project」(WLP) の一環として，パンガ県のタクアパ (Takuapa) の砂と礫の放棄地において*Eucalyptus camadulensis* を劣化地の植生回復のために植樹し，可能な農業の方法を示すためにキャッサバとパイナップルを栽培した。

土地の改良策として耕起・化学肥料施肥 (1.67 ton/ha/yr)・City compost の施肥 (12.5 ton/ha/yr)・およびチガヤ *Imperata cylindrica* のワラ (16.7 ton/ha/yr) によるマルチング (地表の被覆) を試みた。その中でマルチングが樹木にも作物にももっとも良い方法であった。その理由としては，i) 最も暑い季節において土壌の最高温度を下げる，ii) 一年中よい土壌水分条件を保つ，iii) マルチング材料そのものが植物に栄養源として利用され，また土壌微生物の生物的活動を活発化する，iv) さらに現場で雑草を集めることによって容易に実行できることが挙げられる。

不毛地の回復に関する限りは，チガヤによるマルチングと組み合わせた *Eucalyptus camadulensis* の植栽がもっとも見込みの高い方法である。一方，実際的な農業方法の確立，少なくとも持続的にキャッサバとパイナップルの収穫を得ることを，ここのようなごく貧弱な土壌で実現するためには，さらなる努力が不可欠である。