TECHNICAL REPORT

Demonstration of Sustainable Upland Agroforestry Systems in Chinese Taipei

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Taiwan[1] is a mountainous island with lush and diverse forests which occupied 58.5% of the island area. Upland area is vulnerable and unstable, especially huge landslides and debris flow disaster happened frequently in recent decades. However, agricultural practices in upland areas are continuously implemented for livelihood. An agroforestry management system that encourage the farmers to interplant trees on their farmlands can be a solution to harmonize the land use types in upland areas.

The major goal of this project is to develop and demonstrate the sustainable agroforestry systems adaptable in upland areas of Chinese Taipei. The introduction of study sites, which differ in location, elevation and in crop species, were presented. Three of the study sites are selected as the agroforestry demonstration sites, as they have fine examples of crop/tree combination and technological dissemination potentials.

Since soil and water conservation is one of the most concerns in upland area in Chinese Taipei, soil erosion control techniques in agroforestry systems is important. Several useful soil conservation practices which can economically control soil losses are described and suggested. Soil and water conservation treatment on slopeland agroforestry systems according to the classification of slopeland capability is recommended. A demonstration runoff and soil losses monitoring plot, located at Kalala study site, was installed. The data will give us more information on surface runoff and soil erosion of agroforestry system.

Criteria and indicators for evaluating the sustainability of agroforestry systems are categorized under the framework of “Agenda 21” of Chinese Taipei. Three main themes are sustainable environment, sustainable economy, and sustainable society. Critical evaluation indicators under each theme are suggested.

Finally, the recommended agroforestry systems on existing illegal cultivated leased publicly owned forests are provided. The requirements of interplanting density and soil and water conservation treatment are different according to the crop and bench terrace situation. In general, interplanted 600 trees/ha is the minimum requirement. Interplanted tree species should be selected carefully. Moreover, environmental friendly and sustainable practices are necessary.

[1] Chinese Taipei, which makes up islands of Taiwan as well as Penghu, Kinmen, Matsu, and other minor islands. The “Taiwan” in the report represent “Taiwan island of Chinese Taipei”.

LIST OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHARPTER 1. INTRODUCTION

1.1. Background

Taiwan is a mountainous island with lush and diverse forests. The total area of Taiwan island is only 3.6 million ha. Forest area is 2.1 million ha which occupied 58.5% of the island. About 20% (420,000 ha) of the forest area, is plantation, 7% is bamboo forest, and the remaining 73% is classified as natural forest. With more than 260 mountain peaks over 3,000 meters in elevation, the island of Taiwan supports a diverse flora of over 4,000 vascular plant species and a spectrum of six forest types ranging from tropical rain forest to sub-alpine tundra.

Since the mid-1990s, huge landslides and debris flow disaster occurred frequently due to unusual climate change and occasional earthquake. However, the agricultural practices in upland areas are continuously implemented as a consequence of gaining relatively high revenues comparing to those of plain areas. Many landowners even cut trees on their land and planted high revenue agricultural crops instead. Their behaviors not only violate the forest regulations, but also result in soil erosion and water pollution. As a result, how to balance landowners' profit and land sustainability policy is very important.

An agroforestry management system that encourage the farmers to interplant trees on their farmlands can be a solution to harmonize the land use types in the upland areas. Upland area is vulnerable and unstable due to its rugged topography. Yet the communities around the mountain villages rely heavily on the production of agriculture such as fruits, tea, and other cash crops for their livelihood. As it usually takes several years or decades in most cases for a planted tree ready for harvest, most farmers/landowners are not willing to change their cultivated lands into tree plantations due to lack of income for a long period of time. Moreover, domestic timber market is not sound because over 99% timbers in Chinese Taipei are imported. Therefore, combining partial agricultural crop production for short-term income and partial planted trees for long-term forestation as in agroforestry system should be practical.

Although the Chinese Taipei administration has encouraged private individuals, aboriginal people and/or organizations to plant trees by providing free seedlings, rewards, and long-term low interest loans, there are usually not many landowners being qualified to receive the rewards. For example, no agricultural crops on forestland are allowed if landowners want to apply for reforestation rewards. In other words, agroforestry systems are still not encouraged in the Chinese Taipei forestry policy.

In other cases, agroforestry can make it easier for farmers to transit from one type of crop to another when market demand for their products changes. As many upland landowners are getting older while most their children are working in urban areas, they would like to change their intensive-managed farmland into a low input and low labor system, such as forestation. Agroforestry systems will be a good choice during the transition period.

In spite of the advantages of conducting agroforestry systems in upland areas, land management under agroforestry system is still very rare in Chinese Taipei. Related researches in agroforestry in Chinese Taipei are not enough and outdated. More updated technologies in silviculture and plantation management, soil and water conservation, and system evaluation investigations are urgent. Only after we have adequate research results, proper and practical forest policies can be made.

1.2. Purpose

Agroforestry management system can be a solution of balancing agriculture for livelihood with sustainability in upland villages in Chinese Taipei. Under agroforestry system, loss and degradation of agricultural land will be reduced, but resource use efficiency both above and below ground will increase. Moreover, by planting trees we can achieve carbon dioxide reduction. Depending on the tree species interplanted, other advantages of agroforestry systems may include erosion control, soil improvement, windbreak, groundwater management, wildlife habitat, and etc.

The major goal of this project is to develop and demonstrate the sustainable agroforestry systems adaptable in upland areas of Chinese Taipei. Specific objectives including:

1. To develop several different agroforestry management systems to cope with different demands of crop cultivation and tree planting: According to the choice of crop and tree species, the purpose of land owners and the natural conditions of the area, various agroforestry systems and management strategies will be developed in this study. A good agroforestry system should not only achieve sustainability in land use, but also fulfill the needs of local people.

2. To demonstrate the ability of these systems in preventing the destructive landslides and massive surface erosions on cultivated uplands: As huge landslides and massive erosions occurred frequently in upland areas in Taiwan,

awareness of the need for soil conservation has arisen. Interplanting trees in cultivated lands may control erosion through increasing soil cover, providing hedgerow barriers, stabilizing earth structures and etc.

3. To develop the criteria and indicators for evaluating the sustainability of such agroforestry management systems: One of the most important purposes of developing agroforestry systems in this study is to accomplish a sustainable land-use system. Important criteria and indicators for sustainability include the evaluation on biological diversity, forestry and crop products, healthy ecosystems, soil and water resources, carbon dioxide sequestration and etc.

4. To encourage the communities of mountain villages to participate in the development of new agroforestry system(s) and take part in the dissemination of new technologies: Not only individual farmers and stewards of natural resources execute the new agroforestry system(s), people from mountain villages need to know the system(s) and encourage related people to participate in some workshops that were held in the two years. Linking individual and communities actions to forestry authority's concerns and achieving sustainable land use becomes important.

CHARPTER 2. INTRODUCTION OF THE DEMONSTRATION SITES

Five study sites in upland village were established in northern, eastern and central Taiwan, respectively (Fig. 1), as weather and soil conditions are varied in the sites. These experimental sites also differ in elevation (200-300 m, 500-700 m, 1000-1500 m) and in crop species (Table 1). Based on the site area and potentials of technological dissemination, three of the five study sites are selected as the agroforestry demonstration sites. These three sites are larger, and have not only fine examples of crop/tree combination but also potentials on technological dissemination as the farmers in the villages are more active.

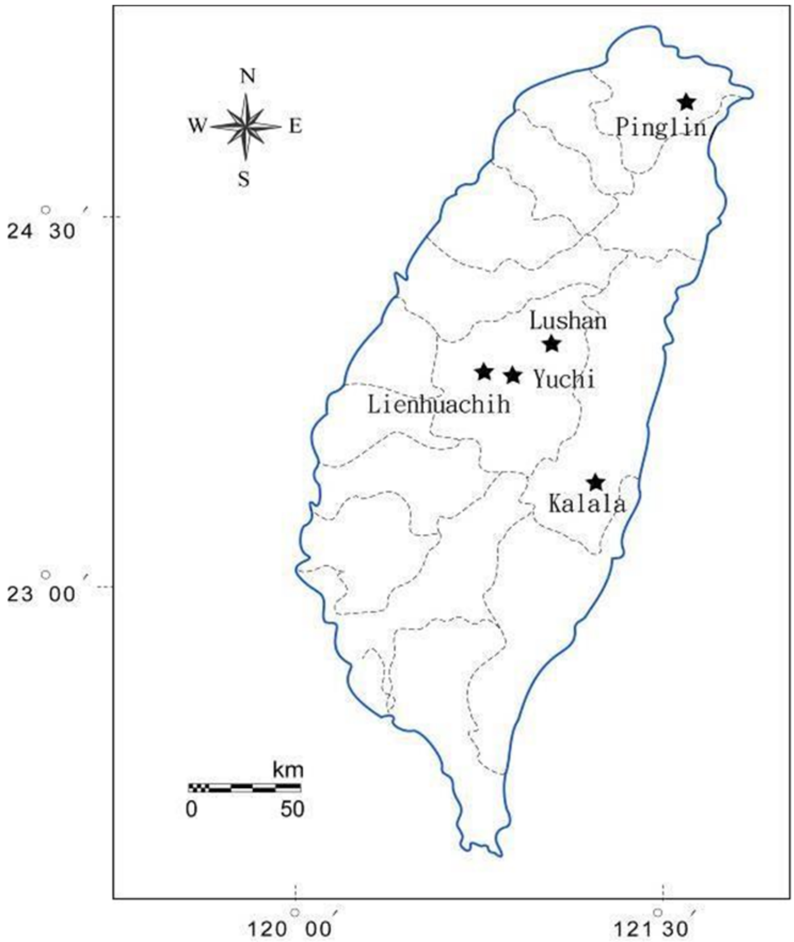


Fig. 1 Map of five study sites

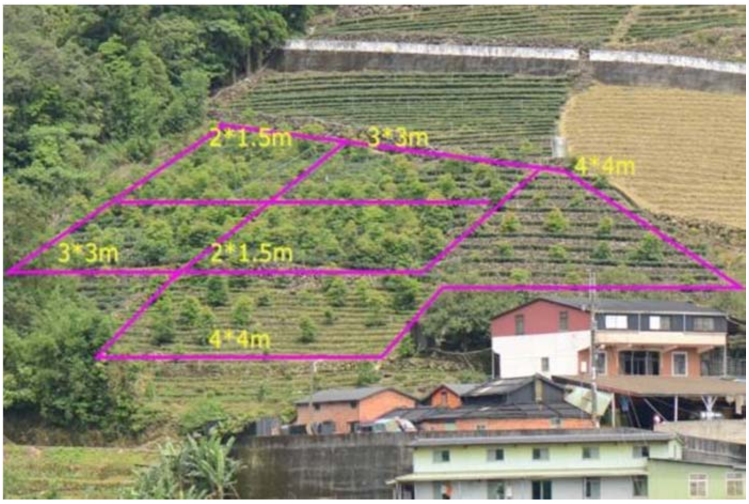
Table 1 Information of five study sites

Site	County/City	Crop	Tree species	Area (m^2)	Elevation (m)
Pinglin*	New Taipei city	Tea	*Cinnamomum kanehirae*	3,800	500
Lushan	Nantou	Tea	*Calocedrus formosana*	10,000	1,460
			Phellodendron amurense var. *wilsonii*	1,200	
			Prunus taiwaniana	1,200	
Lienhua chih	Nantou	Betel nut	*Calocedrus formosana*	1,125	750
Yuchi*	Nantou	Betel nut	*Cinnamomum kanehirae*	3,600	650
Kalala*	Hualien	Coffee	*Cinnamomum osmophloeum*	2,800	200

* Agroforestry demonstration sites

2.1. Pinglin Study Site

Pinglin, this town is very famous for its tea in northern Taiwan. The land owner of Pinglin study site is the village head. Their family has grown tea for 4 generations. They have won many prizes of tea competitions. They decide to transfer from tea to agroforestry for several reasons, including 1) decrease of tea price; 2) old tea trees; 3) concerns about ecology issues.



A. Trees were interplanted at different densities.

B. A weather station was installed at Pinglin study site.

C. Trees have been interplanted for 5 months (photo taken in August 2011).

D. Trees have been interplanted for 13 months. Many trees were higher than tea now (photo taken in April 2012).

Fig. 2 Pinglin study site.

Cinnamomum kanehirae, interplanted at Pinglin, is a unique culture medium for growing a famous and expensive medicinal fungus. As a result, illegal felling problem has been very severe. It is currently very rare in the wild. This is also one of the species that the industry is interested in. *C. kanehirae* was planted at different densities (2x1.5 m, 3x3 m, 4x4 m) (Fig. 2). The effect of varied interplanting density on tea production and environments may be different after a few years.

2.2. Lushan Study Site

Lushan is also famous for its mountain tea. The owner of Lushan study site voluntarily interplanted trees (*Calocedrus formosana*) in his tea plantation around 17 years ago (Fig. 3). These trees are now over 6 meters in height and in good conditions. After we measure the growth of these trees, we also estimate the CO_2 sequestration. They are growing quickly in recent years. They may increase 35% CO_2 sequestration in one year.

Regardless of the fact that these big trees start to shade tea and may reduce part of tea production, the owner still thinks it is worthy. The scenery and ecology value of these trees is significant. Therefore, we interplanted 2 other native tree species, one for medical use and another for ornamental, in 2011. Although only 100 seedlings were planted, the growth data of these 2 species is important for future relative study and agroforestry experience exchange.

A. Two native tree species were interplanted in the slope between tea trees at the beginning of this project.

B. These interplanted big Taiwan Incense Cedar, *Calocedrus formosana*, were 16 years old in 2012.

C. Tea leaves were sampled to see the effect of tree shade

D. Complementary planting at Lushan study site was completed in spring, 2012, before the seasonal rain season.

Fig. 3 Lushan study site.

2.3. Lienhuachih Study Site

Leinhuachih study site is located in the Lienhuachih Research Center, TFRI. One of the Lienhuachih Research Center's important research topics is long-term observation of watershed hydrology and meteorology. Several experiments focusing on the hydrology of betel palm plantation have been installed for many years at this research center.

At Leinhuachih study site, *Calocedrus formosana* was planted at different densities (2x2 m, 3x3 m, 4x4 m, and 5x5 m) under betel palms (2x2 m) (Fig. 4). To compare the soil erosion and runoff under varied tree density, flow measurement weir was set up at each planted density. The effect of varied interplanting density on betel nut production and environments will appear after trees grow up. Accordingly, the most suitable interplanting density will be evaluated.

A. *Calocedrus formosana* were interplanted at different densities under betel palms.

B. Flow measurement weir was set up at this site.

Fig. 4 Lienhuachih study site.

2.4. Yuchi Study Site

At this site, we thin or clearcut betel nut trees. According to the current reforestation reward policy in Chinese Taipei, all crops have to be removed before reforestation. However, we think those betel nut trees may play as nurse trees to protect young seedlings and then improve the success of reforestation. *Cinnamomum kanehirae* were the tree species interplanted here.

Farmlands of betel nut are the main target area in this study. Firstly, betel palm plantations occupy majority of upland agricultural areas. Secondly, the prices of betel nuts are dropping gradually every year since cheap products are imported from abroad. As a result, some farmers are considering changing their crops of betel nut to other crop(s) or even planting trees.

A. Betel nut trees were thinned, clearcut or remained at Yuchi study site.

B. A weather station was installed at Yuchi study site

C. After planted for 2 years, *C. kanehirae* is about 2 m high.

D. The landholder of Yuchi study site also operates a B&B. The interplanting of famous *C. kanehirae* in the backyard may attract visitors.

Fig. 5 Yuchi study site.

The landholder of Yuchi study site also operates a bed and breakfast. The famous *C. kanehirae* interplanted in the backyard may attract visitors to choose to stay in this bed and breakfast. In other words, trees in agroforestry not only can provide forestry products, but also have potential to attract tourists.

The landholder of this study site was the General Secretary of Yuchi Community Association. The residents of this community are at the stage of thinking how to improve and develop or even transform their local industry or business. Agroforestry may help them improve their low-income, labor intensive, and/or environmental unfriendly agricultural land. The landholder may play an important role on promoting agroforestry concept in local community through the community association.

2.5. Kalala Study Site

Kalala, Ruisui Township, Hualien County, Eastern Taiwan is an aboriginal village where A-mei tribe inhabit here. Coffee is their famous agricultural product. Coffee farm is a proper place to develop agroforestry, as coffee is a shade-tolerance species. The Kalala aboriginal community association is well-organized. In addition, agroforestry is closed to their traditional way in A-mei culture. Therefore, agroforestry concept can be disseminated relatively easily.

The study site is to observe the effect of clear-cutting, thinned, or remained betel nut trees interplanted with coffee and Taiwanese camphor (*Cinnamomum osmophloeum)*. Runoff and soil losses monitoring instrument was also installed at this site.

Except the first study site in this village, one more agroforestry site was established later. After some discussions, a few farmers are willing to interplant *Ficus pumila* L. var. *awkeotsang* (Makino) Corner with their betel palms. *F. pumila* var. *awkeotsang*, also known as jelly fig, is an endemic species of Taiwan. The fig is used for jelly desserts or drinks.

A. Kalala site is a betel nut clearcut experiment. Coffee and Taiwanese camphor were planted in March 2011.

B. Agroforestry technology dissemination training workshop at Kalala.

C. Runoff and soil losses monitoring plot was set up at this site.

D. *Ficus pumila* var. *awkeotsang* seedlings were planted at Kalala study site in March, 2012.

Fig. 6 Kalala study site.

CHARPTER 3. SURFACE RUNOFF MONITORING AND SOIL EROSION CONTROL

3.1. Problems in Chinese Taipei

- Natural environment issues

Taiwan's river is steep, short, and flowing rapid. Consequently, stream water is not easy to be stored. Due to the geological fragility and steep terrain, soil is generally shallow and has severe erosion problem. Moreover, there are more Alpine mountains than plains,

- Resource conservation issues

Unevenly distribution rainfall results in distinct dry and wet seasons. Rainfall is mainly in summer, from May to October. Torrential rain of typhoon frequently causes disastrous floods and landslides hazards. During dry season, drought may lead to insufficient water supply affecting the people's livelihood.

- Land use problems

Changes of land-use are complicated. Inappropriate cultivation practices and locations especially in upland areas cause problems, such as landslide and hydrological variability. Moreover, over exploitation of natural resources has damaged the environment.

- Social, economic and other issues

The industries are worried about labor shortage, lack of funds, and low adaptability of the regulations.

3.2. Methods of Solution

- Regulate water flow

To combat flooding, it is important to find ways of reducing peak flow. On the other hand, increasing the base flow in dry season is essential in seasonal flow regulation.

- Improve the quality of water

Appropriate measures of watershed protection of soil and water conservation can maintain and improve water quality.

- Prevent the sand produce

Restrictive development on slope lands is essential on avoiding and reducing sand and silt washed into river and reservoir.

- Reduce flood disaster

Reforestation will improve soil water retention and regulate water flow by reducing peak discharge and increasing base flow.

- Sustainable resource use

Development and utilization of limited resources should be properly planned in advance to achieve sustainable use.

3.3. Surface Runoff and Soil Erosion Monitoring

3.3.1 INTRODUCTION

In 1997, the annual betel nut production income was 13.3 billion NT dollars (or US$400 million) and accounted for 4.2% of the total value of all agricultural products in Chinese Taipei (DAFTPG, 1997). Betel nut or betel palm (*Areca catechu* Linn.) became a major cash crop, because of its high profit, low production cost and strong market demand. Many fruit trees and forests on slopeland in central and southern Chinese Taipei were cleared and converted to betel palm plantations decades ago. The total area of betel palm plantation has increased over the past 30 years, reaching a peak of 56,542 ha in 1997 (DAFTPG, 2013) (Fig 7).

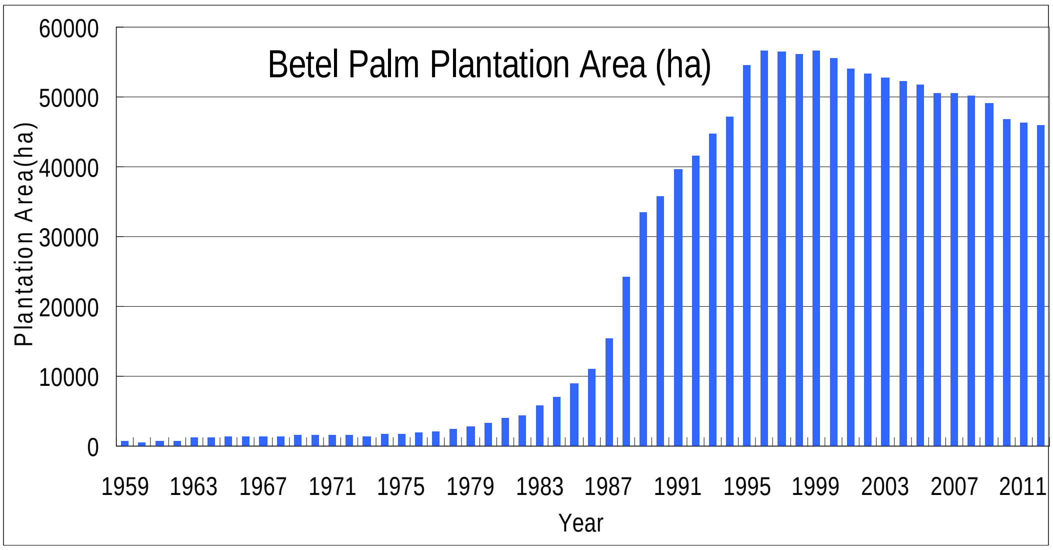


Fig. 7 Betel palm plantation area in Chinese Taipei (1959–2012).

For slopeland affected by rainfall, topography, geology, soil, slope, slope length, vegetation cover, and soil conservation treatments, was the sensitive area of soil erosion and sediment transportation. Betel palm plantation on slopeland caused easily soil erosion (Fig 8). However, there is a lot of amount of information on the hydrological impacts of betel nut planting on slopelands (Wu et al., 1995b, 1997; Lu, et al., 1996; Chen, 1999). The public and conservation groups frequently expressed great concern over the potential negative hydrological impacts of betel palm plantations on steep slopes (Lin, 1999a, 1999b). Based on protection of soil and water resources, planting native plants and efficient land use on slopeland, agroforestry management in betel palm plantation had become an important thinking (Fig 9). To meet the need for more information, this project was constructing mixed plantation plots with clear-cutting, reserved, and thinned betel palm treatments to monitor agroforestry management effect on surface runoff and soil losses for extension and demonstration in the future.

Fig. 8 Betel palm plantation on slopeland may cause serious soil erosion.

Fig. 9 Native plants planting and efficient land using agroforestry management in betel palm plantation on slopeland.

3.3.2 METHOD

i. Overview of the monitoring site

The demonstration runoff and soil losses monitoring plot is located at Kalala with a slope between 20°~25°. Before the experiment was set up, betel palms had been planted more than 20 years and about 15 m high. Due to influence by northeastern monsoon and Pacific Ocean current, the annual rainfall in Hualien is abundant, between 1,349 mm and 2,777 mm. During 2003-2012, the average annual rainfall was 2,165.4 mm (Table 2). The monthly average rainfall was between 57.1 mm and 364.8 mm, and 75% of annual rainfall occurred from May to September. Annual average temperature was between 23.08 ℃ and 23.88 ℃. The high temperature was from May to September, the lowest temperature was 17.9 ℃ in January, and the highest temperature was 28.6 ℃ in July (Table 3)

Table 2 Rainfall records (2003~2012) in Hualien area. (unit:mm).

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Set.	Aug.	Oct.	Dec.	Nov.	Total
2003	33.5	38.5	32	109	7	79.5	25	144	393	250	223	14	1348.5
2004	66	70	84.5	19.5	179.5	142.5	471	51	347.5	121	123.5	307	1983.0
2005	22	109	116	34.5	240	212	492.5	358.5	709	370.5	54	59	2777.0
2006	132	28.5	116	84.5	310.5	235.5	214.5	314	272	99	89.5	5	1901.0
2007	55	9	48	74.6	128.7	163.5	13.2	928.5	347.7	295.6	425	36.7	2525.5
2008	69.5	144	116.4	83.5	72.1	170.4	620.2	111.8	555.2	226.9	80.2	61.8	2312.0
2009	50.6	92.2	92.8	56.4	141.5	320.1	198.6	158.8	325.8	1032.6	38.1	28.1	2535.6
2010	71.3	81.4	36.1	59	94.8	61.4	73.7	60.2	477.5	629.2	104.5	20.2	1769.3
2011	18.1	57.8	95.7	64.2	180.4	83.8	45.5	375	148	487	517.5	126.5	2199.5
2012	53	98.5	95.5	95	398.5	352.5	275.5	485.5	72	82.5	101.5	193	2303.0
Avg.	57.1	72.89	83.3	68.02	175.3	182.1	243.0	298.7	364.8	359.4	175.7	85.1	2165.4

Table 3 Temprature records (2003~2012) in Hualien area. (unit:℃)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Set.	Aug.	Oct.	Dec.	Nov.	Total
2003	17.2	19.2	19.5	23.6	25.5	26.8	29.4	28.7	27.4	24.1	22.9	18.8	23.62
2004	17.2	18.3	19.4	22.6	25.8	26.6	27.6	28.8	26.8	23.9	22.1	20	23.26
2005	17.5	18.6	18	22.9	25.9	27	28.3	28	27.4	25.4	23.3	18	23.36
2006	19.2	19.4	19.9	23.2	25.3	26.4	28.3	28	26.4	25.4	22.9	20	23.70
2007	18.5	20.2	20.8	21.9	25.4	27.7	29.8	27.6	27	25	22.1	20.5	23.88
2008	19	17.1	20.2	23	25	27.3	28.4	28.3	27.2	25.7	22.7	19.6	23.63
2009	17.8	21.2	20.7	21.5	24.8	27.4	28.7	28.9	27.8	25.1	22.7	18.9	23.79
2010	18.5	20.2	21	21.9	25.5	26.5	28.8	28.9	27.1	25.1	21.9	18.8	23.68
2011	16.4	18.7	17.8	21.5	24.7	27.5	28.3	28.7	26.8	24.6	23	18.9	23.08
2012	17.8	18.7	20.8	22.8	25.2	26.9	28.5	28.1	26.8	24.3	21.4	18.8	23.34
Avg.	17.91	19.16	19.81	22.49	25.31	27.01	28.61	28.4	27.07	24.86	22.5	19.23	23.53

ii. Analysis of water balance

Potential evapotranspiration is estimated according to Thornthwaite's empirical formula. The formula was as follows:

$$ET = 1.62 \times b \times (10T_m / I_H)^a$$

$$I_H = \sum_{M=1}^{12} (T_M / 5)^{1.514}$$

$$a = 6.75 \times 10^{-7} I_H^3 - 7.71 \times 10^{-5} I_H^2 + 1.791 \times 10^{-2} I_H + 0.492$$

ET is monthly potential evapotranspiration (cm), T_M is mean monthly temperature (℃), a is an exponent derived from the heat index (I_H), b is the daylight coefficient, and I_H is annual heat index. Then change of soil moisture, and analysis deficit and surplus water on water balance were calculated.

iii. Observation of runoff and erosion

The observation subplots in experimental design were clear-cutting, reserved and thinning (Fig. 10) to measure the effect of agroforestry planting on runoff and soil losses in betel palm plantation. The Universal Soil Loss Equation (USLE) was a widely used mathematical model that described soil erosion processes (Hudson, 1993; Wischmeier, 1960, 1971, 1978). The experimental subplots designs followed the specifications of Universal Soil Loss Equation (USLE) (22.3 x 10 m). With the same designs, our results can be compared to others easily. The subplots were fenced with steel plates that directly inserted into soil depth of 15 cm and above soil surface of 15 cm. The lower reach of each subplot had a surface runoff collection trough to collect the surface runoff and sediment. Each subplot was installed with a pressure-type stage gauge to record the water stage and turbidity gauge (Fig. 11), as well as the changes of water turbidity when it is raining.

After collecting water level and turbidity of surface runoff, the discharges were exchanged by rating curve (Fig. 12) and total runoff amount was calculated from time lapse of 2 minutes. Sediment amount was calculated by runoff amount multiple of turbidity. The rating curve of discharge and water level was that:

$Y=3.85 X^{2.5}$，X: water level (cm), Y: discharge (cm^3/s)

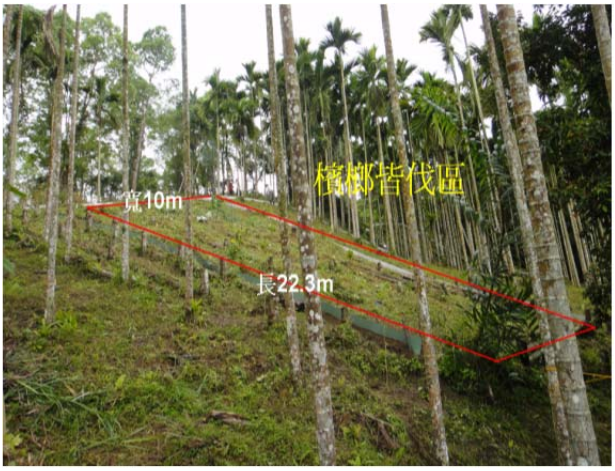
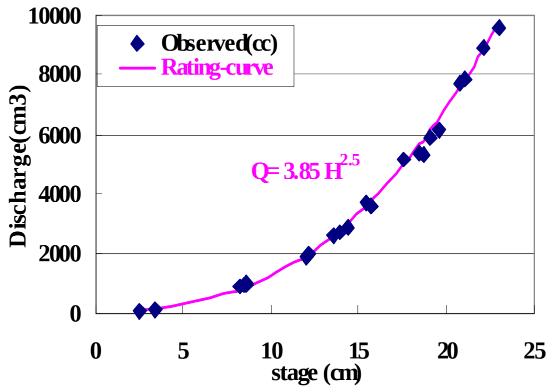


Fig. 10 Area of a subplot at Kalala site.

Fig. 11 V-notch weir installed with a pressure-type stage gauge to record the water stage and turbidity gauge.



$Q=8/15C(2g)^{1/2}\tan(1/2\,\theta)H^{5/2}$,
$\theta=30^{O}$, $\tan(1/2\,\theta)=\tan 15^{O}=0.268$
$C'=8/15C(2g)^{1/2}\times 0.268$
$Q=C'H^{5/2}$

Fig. 12 Formula and discharge-water level rating curve.

3.3.3 CHARACTERISTICS OF BETEL PALM

The crown of betel palm, as illustrated in Fig. 13, had six leaves with total leaf area of 8.47 m^2. The leaf area index (LAI) of betel palm was 1.36 which was rather low as compared to 9 of the LAI of natural hardwood forests and 8.4 of the LAI of 30-year old China fir forests (Lin, 1995). This gave reasons for lower LAI and lower crown closure of betel palm plantations in comparison to China fir and natural hardwood plots. The tall, single-layer and wide spacing canopy between planted betel palms led to lower interception losses (Fig. 14), higher mixed throughfall and stem flow, and higher net rainfall (Fig. 15). Plots planted with betel palms had lower infiltration (Fig. 16), higher surface runoff and higher erosion than forested sites (Cheng, 2008). These hydrological characteristics were related to factors such as crown cover, soil organic content and soil porosity in betel palm plantations. The crown characteristics of betel palm were rather different from those of fruit trees and China fir.

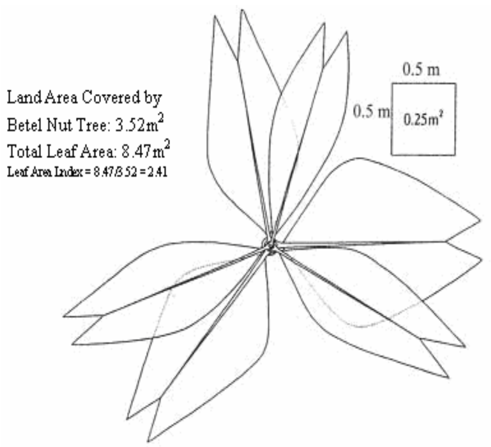


Fig. 13 Bird’s-eye view of a typical betel nut tree crown (left) and betel nut plantation (right).

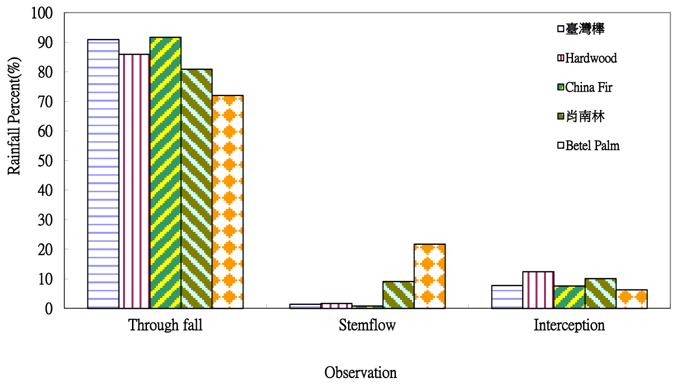


Fig. 14 Tall, single, layer and wide spacing canopy of betel palm.	Fig. 15 Percentages of throughfall, interception and stem flow for different vegetation covers.

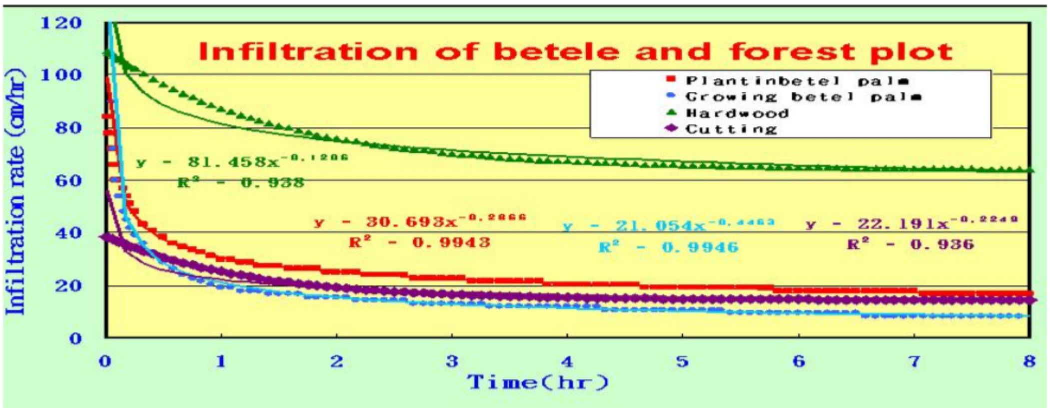


Fig. 16 Plots planted with betel palms had lower infiltration.

3.3.4 WATER BALANCE AND RUNOFF RATIO FORECASTING

The temperature and rainfall data of Hualien area were collected to estimate potential evapotranspiration with Thorntwaite's formula. Then change of soil moisture, and analysis deficit and surplus water on water balance were calculated (Table 3). In rainy season, monthly rainfall is usually greater than potential evapotranspiration, and actual evapotranspiration is equal to potential evapotranspiration. Annual potential evapotranspiration in Hualien area is estimated 1,327.1 mm, and annual calculated actual evapotranspiration is 1,304.8 mm. The deficit water amount is 22.9 mm. The surplus water amount is 861.4 mm. The runoff percentage, the ratio of surplus and rainfall amounts, is equal to 39.78%.

Table 4 Water balance at Hualien area.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Set.	Aug.	Oct.	Dec.	Nov.	Total
Avg. monthly rainfall(mm)	57.1	72.9	83.3	68.0	175.3	182.1	243.0	298.7	364.8	359.4	175.7	85.1	2165.4
Avg. temp.(℃)	17.9	19.2	19.8	22.5	25.3	27.0	28.6	28.4	27.1	24.9	22.5	19.2	23.5
Potential ET(mm)	41.3	48.3	61.1	90.9	138.6	164.9	200.1	189.0	150.2	113.9	78.6	50.0	1327.1
Soil moisture change (mm)	15.8	24.6	22.2	-22.9	36.7	17.2	42.9	109.7	214.5	245.6	97.0	35.1	
Soil moisture content(mm)	120	120	120	97.1	120	120	120	120	120	120	120	120	
Actual ET(mm)	41.3	48.3	61.1	68.0	138.6	164.9	200.1	189.0	150.2	113.9	78.6	50.0	1304.0
Deficit water amount (mm)	0.0	0.0	0.0	22.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.9
Surplus water amount (mm)	15.8	24.6	22.2	0.0	36.7	17.2	42.9	109.7	214.6	245.5	97.1	35.1	861.4

3.3.5 OBSERVATION OF RUNOFF AND SOIL EROSION

Most rainfalls during the dry season from January to March is little, about 57~83 mm in Taiwan. In this period, the soil is usually dry and all the rainfall will be absorbed in soil, except during occasionally heavy rainfall events while rainfall excess converts into surface runoff. During rainy days in 2012, 19 events of surface runoff and turbidity were measured (Table 5). Surface runoff and turbidity was calculated from the observation data (Fig. 17). The total rainfall amount of the 19 events was 577.0 mm. Surface runoff amounts of clear-cutting, reserved and thinned were 38.9 mm, 92.0 mm and 88.8 mm, respectively. Runoff rate of clear-cutting, reserved and thinned were 6.7 %, 15.9 % and 15.4 %, respectively (Table 6).

Table 5 Rainfall, surface runoff and soil losses calculation of each storm event.

Date	Rainfall (mm)	Runoff (mm)			Soil losses (kg)		
		Clear-cutting	Reserved	Thinned	Clear-cutting	Reserved	Thinned
3/19 14:38~04/19 16:18	38	6.582	14.173	0.032	0.414	2.511	2.151
4/16 12:34~04/19 08:00	21	0.812	0.823	1.328	0.048	0.162	0.112
4/26 06:10~4/27 00:48	13	1.207	0.960	0.959	0.214	0.227	0.209
6/07 14:46~6/07 15:24	7	0.246	0.290	0.845	0.044	0.070	0.205
7/21 23:20~7/25 11:28	58	2.056	2.321	2.390	0.396	0.321	0.315
7/22 15:06~7/24 03:24	12.5	0.518	0.530	0.489	0.101	0.078	0.065
7/24 16:02~7/25 11:28	17.0	0.413	0.669	0.227	0.079	0.092	0.024
7/25 18:58~7/27 07:58	19.5	0.394	0.981	2.055	0.077	0.148	0.205
7/25 20:30~7/25 23:28	14	0.340	0.728	1.716	0.065	0.111	0.160
7/26 18:32~7/26 22:20	5.0	0.072	0.255	0.089	0.014	0.31	0.017
7/28 03:00~7/2/ 18:00	44.0	2.315	8.924	11.822	0.446	1.297	0.792
7/30 12:26~8/03 05:58	112.5	4.456	9.350	13.087	0.838	1.257	1.228
8/15 00:00~8/18 22:00	38.0	1.781	4.555	2.814	0.429	0.752	0.505
8/15 06:10~8/16 07:58	35.0	1.757	5.543	5.244	0.424	0.829	0.742
8/18 03:30~8/16 07:58	2.0	0.056	0.067	0.104	0.014	0.011	0.019
8/23 11:00~8/24 05:14	66.5	5.922	12.528	11.952	1.002	2.036	1.057
8/27 18:00~8/28 12:20	67.5	5.388	25.083	19.903	0.708	3.328	1.441
9/14 21:40~9/29 06:52	12.5	2.680	1.589	12.108	0.584	0.288	2.123
10/23 18:16~10/24 5:26	7.0	1.861	2.613	1.647	0.450	0.507	0.330
Total	577	38.855	91.982	88.810	6.347	14.335	11.700

Table 6 Rainfall, surface runoff and soil losses amounts of monitoring subplots.

	Clear-cutting	Reserved	Thinned
Rainfall (mm)	577	577	577
Runoff (mm)	38.855	91.982	88.810
Runoff rate (％)	6.7	15.9	15.4
Soil losses (t/ha/y)	1.068	2.412	1.969
Erosion rate (mm)	0.075	0.164	0.126

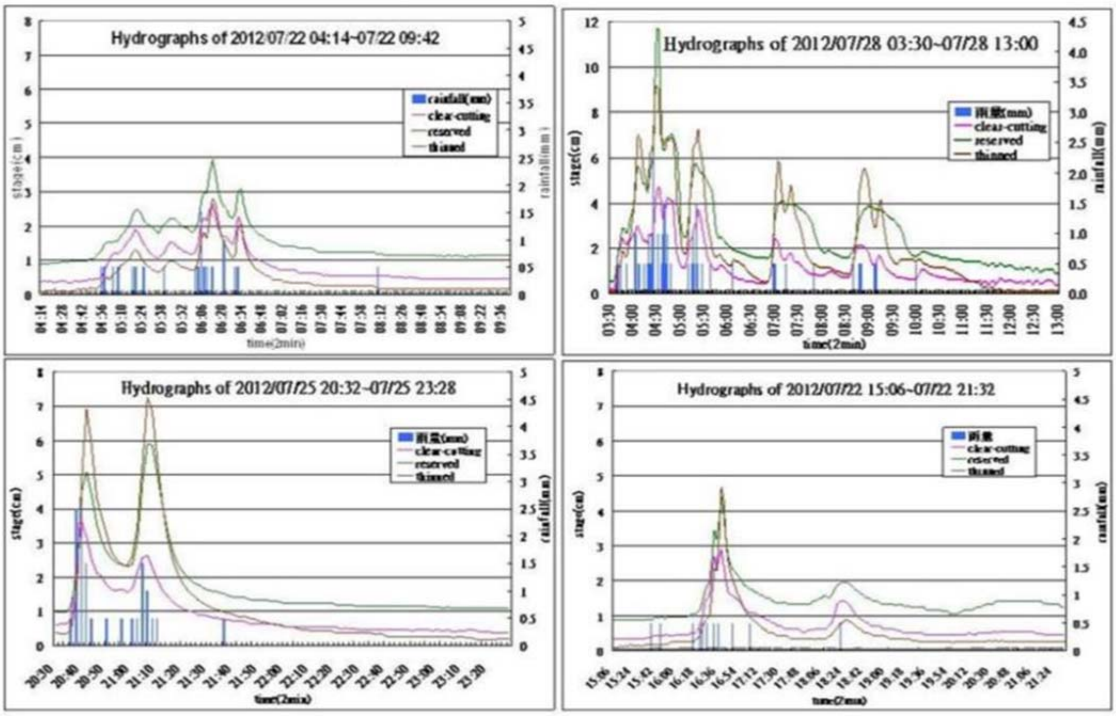


Fig. 17 Surface runoff hydrograph of each storm event on monitoring subplots.

The occurrence of soil erosion results from the shear force of surface runoff. Shear force takes place due to the surface runoff flowing on the soil surface. If the soil erosion resistance is smaller than the shear force of surface runoff, then the sheet erosion follows. Otherwise, the soil erosion will not take place on the soil surface. Soil erosion of clear-cutting, reserved and thinned were very few and their amounts were 6.3 kg (1.068 t/ha/y), 14.3 kg (2.412 t/ha/y) and 11.7 kg (1.969 t/ha/y), respectively. The surface runoff and soil erosion amount of clear-cutting subplot was obviously lower than those of reserved and thinned subplots. This is due to the well ground cover and different slope gradient that gradient of clear-cutting plot is lower than reserved and thinned.

3.3.6 EFFECT OF AGROFORESTRY PLANTING IN BETEL PALM PLANTATION

When there is no rainfall for a long time, soil will be dry and all the rainfall will be absorbed in soil except during occasionally heavy rainfall events. The occurrence of soil erosion results from the shear force of surface runoff. If the soil erosion resistance is smaller than the shear force of surface runoff, then the sheet erosion occurs. Based on our runoff and soil erosion experiments of agroforestry area in betel palm plantation at Kalala, the rainfall amount of 19 events was 577.0 mm.

Surface runoff amounts of clear-cutting, reserved and thinned were 38.9 mm, 92.0 mm and 88.8 mm, respectively. Runoff rate of clear-cutting, reserved and thinned were 6.7 %, 15.9 % and 15.4 %, respectively.

The tall, single-layer planted betel palms with wide spacing canopy among led to lower interception losses, higher mixed throughfall and stem flow, and higher net rainfall. Plots planted with betel palms usually have lower infiltration, higher surface runoff and higher erosion than forested sites. These hydrological characteristics were related to factors such as crown cover, soil organic content and soil porosity in betel palm plantations. The crown characteristics of betel palm are rather different from those of fruit trees and other plantation tree species. The forest interception will consume water which is evaporated back to atmosphere. Basically, adding tree planting area in agroforestry will increase the consumption of evaporation and can contribute to reduce runoff and surface erosion. Erosion rate of clear-cutting, reserved and thinned were very few and their amounts were 0.075 mm, 0.164 mm and 0.126 mm, respectively. Erosion rates of monitoring subplots are lower than average erosion rate 5.2mm per year in Chinese Taipei.

3.4. Soil Erosion Control Techniques

With collaboration by concerned universities and agricultural research institutes, a series of experimental projects were conducted to develop modern soil conservation measures for different field crops on slopeland since 1952. In many experimental projects, runoff plots are distributed on slopes from 20 % to 55 %. Data and information obtained from these experimental projects have been contributed to the compilation of “Soil conservation handbook”. This handbook includes 24 soil conservation practices, namely, hillside ditches, orchard hillside ditches, grass planting on hillside ditches, bench terraces, planting grass on risers, grass barriers, stone walls, broad based terraces, contour planting, cover crops, mulching, green manure, windbreaks on slopeland, farming path, link road, grassing farm roads, vegetative cover on side slope, diversion ditch, grass water way, stone ditches, brick ditches, prefabricated ditch or flume, culvert, and drop structure. All these practices were proved helpful and effective for control of soil erosion and promotion of slopeland development in Chinese Taipei.

Due to different crop types, surface cover time and coverage degree, mulching practicability, and residual amount, these relations on soil fertilizer consumption, soil erosion, and so on are different. The required tillage management is different too. All are sufficient to determine the feasibility of soil and water conservation methods, and affecting the need for soil and water conservation program.

Field trials and soil loss observations had been carried out on slopeland planted with tea, pineapple, sugar cane, bananas, oranges, mangoes, litchis, hemp, mulberry, bamboo, lemon grass, cassava, grapefruit, and forage grass. Induction of the data obtained, these crops are divided into three categories: short-term tillage, cultivated crops and fruit orchards. Briefly describe the soil and water conservation methods are as follows:

- short-term tillage

Such as tea, lemon grass, cassava, miscellaneous and forage grass, these short-term farming crops whether contour density planting or high beds planting, and crop rotation adjusting on the rains, are unable to control soil erosion to effective levels and very serious. So that grass strips should being used to form bench terraces.

For high density tea planting, canopy of tea tree is so closed that ground is covered well. Tea tree is called the best cover in Ceylon tea plantation. In order to save constructing bench terraces wages in tea plantation, narrow terrace and grass strip mainly are used to control soil erosion.

- cultivated crops

Pineapple, sugar cane, mulberry and bamboo are main long-term cultivation crop. In pineapple and sugar cane fields, soil conservation experiments proved that contour planting and mulching agronomic treatments on soil loss control were effective. The data is proven that these crops planting on slopeland are not need constructing bench terrace. Pineapple residual can be applied to lines mulching. This saves the costs of mulching material of purchase and transport. After residual mulching, the amounts of chemical fertilizer can be reduced the one-third. It is not affecting the production of pineapple. Such methods used on slop gradient 20 degrees, it remains in effect. Sugar cane plantation using sugar cane leaf and roots as mulching, as well as early farming, these were increased cover rate to mitigate effect of soil losses in the rainy season. Mulberry, bamboo and hemp in rows Bahia grass strip cover, beds planting, and mulching around plants have been proven practicable. And long-term crops planting using hillside ditches coordinated agronomic methods can achieve effective control soil losses.

- fruit orchards

Hillside orchard is an important industry in Chinese Taipei, which mainly is banana, citrus, mango, and litchi. In "Banana terrace cultivation and agronomic methods compared test", knew that Bahia grass strip covered, mulching and grass strip method can replace the construction of bench terraces. From "Young citrus comparative experiment of soil and water conservation methods", we learned that mulching, Bahia grass strip covered and mulching, Bahia grass garden covered and mulching, and all kinds of bench terraces are valid. Mulching and horizon terrace has almost no soil loss. The "Mango soil and water conservation benefit experiment" also proves that the Bahia grass-covered amount of soil erosion is the least, followed by grass strip cover and mulching, wind-love grass mulching, and net cultivation is most.

Initial yield of win-love grass mulching is the most, net cultivation next, strip cover following, and Bahia grass-covered the lowest. Measuring soil organic matter, all Bahia grass treatments are highest and net cultivation treatment is the lowest. Bahia grass treatments in soil conductivity and infiltration rate are the highest, but low bulk density showed that their soil physical property are better. Covered Bahia grass and fruit trees have nitrogen fertilizer competition, using Bahia grass strip covered and mulching can be improved. The result of testing and observation soil erosion control in Litchi and bamboo fields, trends are consistent.

Based on the above results, knew that cover crops and mulching on soil losses control are simple and economic methods. Hill ditches implemented in orchards, instead of costly bench terraces, can improve soil properties and save weeding of cultivation that in fact have multifaceted benefits.

3.5. Slopeland Classification in Chinese Taipei

Chinese Taipei has developed a standard for slopeland capability classification when considering both effective soil depth and average slope. According to the "slopeland capability classification standard" in Chinese Taipei, lands can be categorized into six classes (Table 7). Land in Class 1-4 is suitable for agriculture and animal husbandry use. Land in Class 5 is suitable for forest land. Some areas classified in Class 6, which are either exposed parent material or having severe soil erosion/landslide problem, are for conservation and reservation use only.

Table 7 Slopeland capability classification standard in Chinese Taipei

Effective soil depth (cm)	Average slope (%)					
	<5	5-15	15-30	30-40	40-55	>55
Very deep >90	Class 1	Class 2	Class 2	Class 3	Class 4	Class 5
Deep 50-90	Class 1	Class 2	Class 3	Class 4	Class 4	Class 5
Shallow 20-50	Class 2	Class 3	Class 4	Class 4	Class 4/ Class 5	Class 5
Very shallow <20	Class 4	Class 4	Class 4	Class 4/ Class 5	Class 5	Class 5
Land for conservation and reservation	Class 6					

3.6. Recommended Soil and Water Conservation Treatment on Slopeland Agroforestry Systems

Recommended soil and water conservation treatments on slopeland agroforestry systems are listed below. Four types of land are classified according to effective soil depth and average slope (Table 8). For areas with shallower soil and steeper slope, more soil and water conservation treatments are required. Class 6 land as categorized by "slopeland capability classification standard" is not suitable for agroforestry; therefore, it is not included here.

Table 8 Recommended agroforestry system classification standard on slopeland

Effective soil depth (cm)	Average slope (%)					
	<5	5-15	15-30	30-40	40-55	>55
Very deep >90	Type 1	Type 1	Type 1	Type 2	Type 2	Type 4
Deep 50-90	Type 1	Type 1	Type 2	Type 2	Type 2	Type 4
Shallow 20-50	Type 1	Type 2	Type 2	Type 2	Type 3	Type 4
Very shallow <20	Type 2	Type 2	Type 2	Type 3	Type 4	Type 4

i. Type 1

-Slope less than 5%, soil depth more than 50 cm;

-Slope less than 5%, soil depth among 20 and 50 cm;

-Slope: 5- 15%, soil depth: > 50 cm;

-Slope: 15-30%, soil depth: > 90 cm

Soil and water conservation treatment: > 70% grass cover in perennial orchard

ii. Type 2

-Slope: 40-55%, soil depth: > 50 cm;

-Slope: 30-40%, soil depth: > 20 cm;

-Slope: 15-30%, soil depth: <90 cm;

-Slope: 5-15%, soil depth: <50 cm

Soil and water conservation treatment: > 70% grass cover in perennial orchard, hillside ditch

iii. Type 3

-Slope: 40-55%, soil depth: 20-50 cm;

-Slope: 30-40%, soil depth: <20 cm

Soil and water conservation treatment: > 70% grass cover in perennial orchard, bench terrace

iv. Type 4

- Slope: > 55 %

Soil and water conservation treatment: planting > 600 trees/ha, no fruit tree is suggested; if 600 trees can't be planted evenly, contour planting of remaining trees along the bottom edge is recommended. The purpose is to establish a forest buffer strip for the protection of soil and water.

CHARPTER 4. CRITERIA AND INDICATOR FOR EVALUATING THE SUSTAINABILITY OF AGROFORESTRY SYSTEMS

"Sustainable development" can be defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (the World Commission on Environment and Development, 1987). The project team worked cooperatively to select criteria and indicators for evaluating the sustainability of agroforestry systems based on references, experiences, study site observations, and discussion with farmers/communities. The report is just a preliminary result of the study. Indicators may be adjusted after more discussions among different parties and collecting more updated data in the field.

According to "Chinese Taipei Agenda 21: a conceptual framework for sustainable development", there are three main themes of the conceptual framework: environment, economy and society, respectively. In this report, criteria and indicators for evaluating the sustainability of agroforestry systems in Chinese Taipei are categorized under this conceptual framework. To be efficient temporally and financially, a couple of appropriate key indicators chosen from the total list when evaluating one site are suggested. A key indicator means the most sensitive or most needed of improvement factor at a particular site.

4.1. Sustainable Environment

Due to unstable geological conditions in upland areas, soil erosion and landslides occur frequently in Chinese Taipei. In seeking to satisfy farmer's basic living needs, we should do our best to protect the natural environment at the same time. Moreover, protecting other forms of life and maintaining the biological diversity are essential. Although Taiwan is a small island, abundant variety of biological resources and species inhabit here. A healthy and sustainable environment is the foundation of human life. Three sub-themes in this themes and important criteria or indicators are listed below.

Sub-theme	Indicator	Criteria/basic information
1. Nature conservation	● Change in biodiversity (in heredity, species, or ecosystem level), population of specific indicator group	Monitoring diversity or population of key group, such as endangers species population or total species richness
	● Tree/agricultural crop coverage area	Increasing tree coverage
	● Supply of water resource	Effective water resource
	● Landside area/ratio	Occurrence of landside
	● Degree of erosion	Monitoring soil erosion
	● Greenhouse gas emission	Greenhouse gas emissions due to agricultural activities
	● CO_2 sequestration	CO_2 sequestration due to tree planting
	● Microclimate change (temperature, rainfall, humidity)	Long term monitoring the change of microclimate
2. Pollution prevention and control	● Pesticide usage rate per hectare	Compare pesticide usage rate of agroforestry land to farmland
	● Fertilizer usage rate per hectare	Fertilizer use efficiency
	● Pesticide residual in soil/water	Pesticide pollution in soil/water
	● Fertilizer residual in water	Fertilizer pollution in water
3. Environmental planning	● Developed land ratio	Establishing reasonable land use plan
	● Road ratio	Minimizing impact of road construction

4.2. Sustainable Economy

From the economic perspective, sustainable development seeks efficiency gains from capital to ensure the daily needs of the people while maximizing the net benefit of economic activities. With careful design and purposefully arrangement, agroforestry may bring in sustainable income. Customer- or market- oriented agroforestry systems will ensure the success in the future. It is possible that the income is not from agroforestry product directly. For example, subsidy from government and visits from eco-tourism are added profit.

Sub-theme	Indicator	Criteria/basic information
1. Clean production	● Area of organic cultivation	Area under organic farming
	● Ratio of cultivated land	Proportion of land area for arable and permanent cropland
	● Area of agroforestry land	Area under agroforestry system
	● Change rate of land use from cultivation to agroforestry	Increasing agroforestry land
2. Labor	● Labor productivity index	A measure of how much output (i.e. forestry product) is produced per unit of input
	● Unemployment rate in the village	Unemployment-population ratio, agroforestry may reduce unemployment rate
3. Income	● Production value of agroforestry	Total output value of agroforestry products
	● Annual income per person/household	Increasing personal/household income
	● Financial misery index	The sum of the inflation rate plus unemployment rate
	● Ratio of low-income families	Proportion of population living below the lowest living expense standard
	● Subsidy for environmental friendly practices or green production	Encouragement of environmental friendly practices/green production
4. Green industries	● Visits from eco-tourism	Agroforestry may promote proper eco-tourism

4.3. Sustainable Society

Although Chinese Taipei is already highly urbanized, community living still remains an important part in the daily life of our citizens. The establishment of a secure and harmonious society will assure members of village willing to stay.

People born in aboriginal or small isolated villages used to move to cities for work. The pressure from living in cities often makes them feeling distressed. A sustainable society will encourage people to move back to their hometown and may lead to a more satisfactory and happier life.

For improvement toward becoming a sustainable society, we need to follow the path of developing communities that are energetic, complete, ecologically friendly, and culturally unique. Participating of the public in the community will help the development of sustainable society. Support from the government is correspondingly necessary.

Sub-theme	Indicator	Criteria/basic information
1. Population and health	● Population density	Change of population in an area
	● Number of people returning to village from city	People returning to hometown village from city may benefit the village
	● Structural change in population	Increasing the proportion of persons at working ages is the most critical
2. Public participation	● Civil participation of agroforestry	Except farmers, the participation of other citizens
	● Community-based participation of agroforestry affairs	Strengthen community cooperation
3. Dissemination	● Financial support in promoting agroforestry	Financial support may initiate agroforestry more effectively
	● Support from agroforestry technical team	Farmers need updated technology in agroforestry frequently

CHARPTER 5. RECOMMENDED AGROFORESTRY SYSTEMS ON EXISTING ILLEGAL CULTIVATED LEASED PUBLICLY OWNED FORESTS

For those existing illegal cultivated leased publicly owned forests in Chinese Taipei, some areas (based on the land slope and effective soil depth conditions) may practice agroforestry when considering both environmental conservation and farmers' livelihood. If areas should only be forestland for a long run for conservation reasons, an agroforestry system may be a good choice during the transition period. Suggestions and conditions are discussed as following.

5.1. Interplanting Density and Soil and Water Conservation Treatment

- Betel nut plantations

Betel nut plantations should interplant tress at least 600 trees/ha in density. No clearcutting of existing betel palm is suggested before forestation planting. The clearcutting practice may lead to soil losses; meanwhile, betel palm may play as nurse tree to protect planted seedlings. When interplanted trees grow high enough and betel palms are too tall for harvest, betel palms can be removed or injected to die.

- For perennial orchards and tea gardens with bench terraces

Trees should be interplanted at least 600 trees/ha under contour strip system on slopes between bench terraces. If 600 trees can't be planted on the slope per ha, the remaining trees can be planted along the bottom edge of the orchard/garden to establish a forest buffer strip. Over 70% coverage of grass mulching on the bench (flat part) is recommended.

- For perennial orchards and tea garden without bench terraces

Trees should be interplanted 600 trees/ha in appropriate section (e.g. steep slope or serious soil erosion area) in patches or alone contour strip. Distance between contour planting strips should be less than 10 m. If 600 trees can't be planted on the strips or patches per ha, the remaining trees can be planted along the bottom edge of the orchard/garden to establish a forest buffer strip. Over 70% coverage of grass mulching on the bench is recommended.

5.2. Interplanted Tree Species and Practices

Interplanted tree species should be selected carefully. First of all, the environmental conditions have to be suitable for the species growth. To encourage leasers joining forestation, interplanting tree species which is potentially profitable when it is ready to harvest in the future is recommended, such as *Cinnamomum kanehirae*, *Calocedrus formosana*, and *Cinnamomum osmophloeum*.

Environmental friendly and sustainable practices are essential. For example, chemical herbicide should be banned. Applying sustainable weed management systems may reduce both herbicide dependency and the burden of manual weeding. If fertilization is necessary, unfermented animal feces should be avoided as which may contaminate water.

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