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Land Characteristics and Soil Erosion in Relation to Slope Farming in the Highlands of Candikuning, Bali, Indonesia

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Abstract

Many environmental problems, such as soil erosion, affect upland and hillyland agricultural systems. In a study conducted in Candikuning village, Bali, Indonesia, biophysical characteristics and soil erosion were determined in relation to slope farming.

The area is dominated by forests and vegetables dry land with slopes ranging from moderate to steep. Soils in the area have medium to high fertility levels and the major soil types are Andosols and Regosols.

Erosion was found to occur slightly in the forestland but was more severe in the dry and shrub lands especially in areas with slope more than 15%. As such, appropriate soil and water conservation measures are needed to achieve sustainable farming systems in these areas.

Key words : soil erosion, slope farming, highland, Bali, Indonesia

Introduction

According to the Bali Local Government (1995), population growth rate in the island is quite high during the last twenty years. Coupled with a limited area for cultivation of food crops, the need to produce more food to meet the demands of an increasing population has become highly imperative.

Faced with this reality, farmers are forced to cultivate even the sloping lands, which are oftentimes unsuitable for annual crops. The intensive nature of annual crop cultivation in slope lands can cause soil erosion. Without appropriate soil conservation measures, soil productivity will decrease and erosion materials from upslope can accumulate in the low-lying areas as sediments. As a result, land and water resources will be degraded.

This study was conducted in order to generate basic data related to land characteristics and degree of soil erosion in sloping farmlands. The findings of this study can also be used as important information or input to future research activities.

Materials and Methods

The research was conducted in Candikuning village, district of Tabanan, Bali, Indonesia which had an elevation between 1,200 m to 2,100 m above sea level and having coordinates 8°14′30″S to 8°18′30″S latitude and 115°7′35″E to 115°11′30″E longitude. Landform units found in the village are cauldron valleys in the northern and northwestern parts, which are undulating to rolling, and volcanic ridge in the

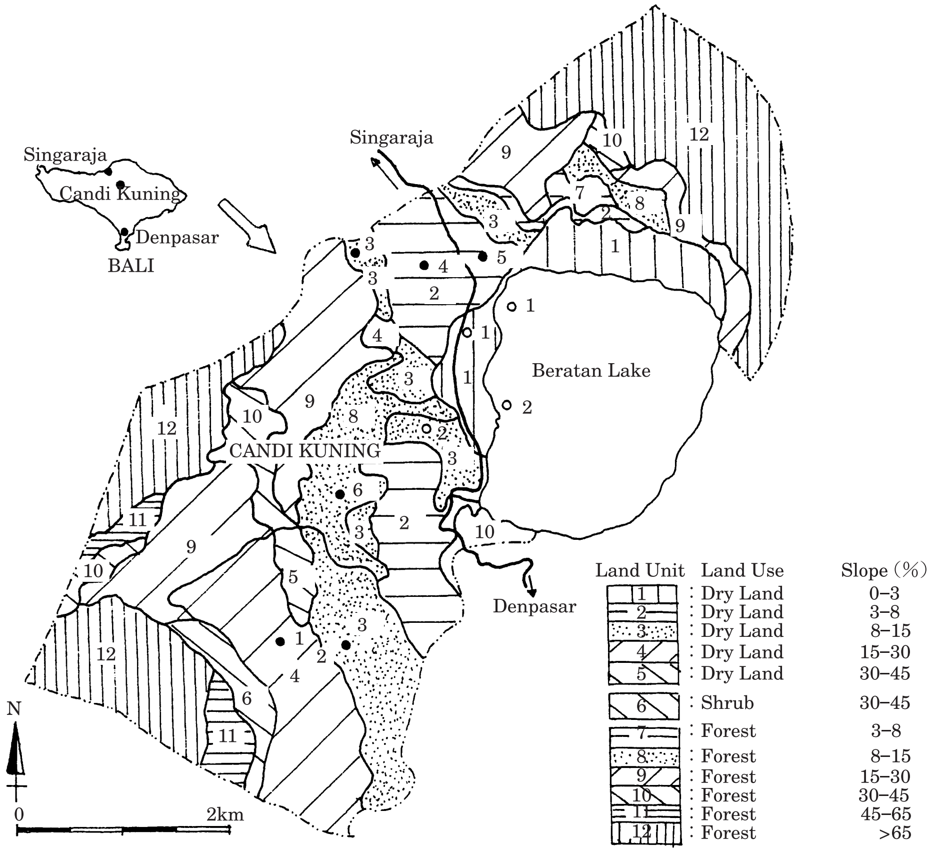

Fig. 1 Land unit map of Candikuning, Tabanan, Bali, Indonesia

south and western parts where the topography is hilly to mountainous. The soil types are Gray Brown Andosols whose parent material is intermediary volcanic ash and Gray Regosols which have intermediary tuff volcanic ash as parent material.

Primary data on climatic characteristics, land use, soil characteristics, topographic features, slope patterns and status of erosion were obtained through direct observation, soil sampling and farmer interviews. Secondary data was also collected. A field survey was done to ascertain the dominant and existing land uses in the area. A land use map of Bedugul area produced by the local government of Bali was used as a baseline map.

The boundaries of each land use were delineated using an air photography, topographic map (1 : 25,000) and a slope map where 12 land units were identified as presented in Fig. 1.

Soil sampling was done based on slope sequence, slope class and land status. The soil's physical and chemical analysis were done at the Laboratory of Soil Science in Udayana University. The degree of erosion was evaluated using the Universal Soil Loss Equation (USLE) formulated by Wischmeier and Smith (1978) which states that :

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where, A is the predicted soil loss (t ha^{-1} y^{-1}), R is the annual rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}), K is the soil erodibility factor (t ha h MJ^{-1} ha^{-1} mm^{-1}), L is the slope length factor, S is the slope steepness factor, C is the cover and management factor and P is the conservation support practice factor.

Each component of the USLE as applied to the research site was determined based on cer-

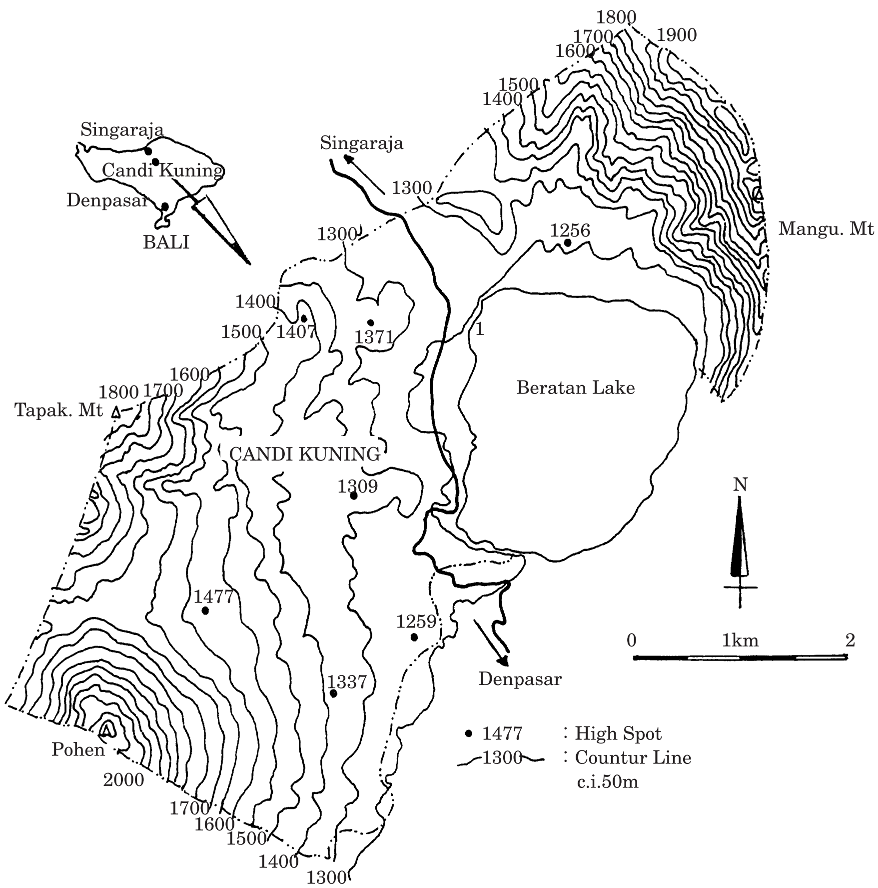

Fig. 2 Topography map of Candikuning, Tabanan, Bali, Indonesia

tain equations such that the rainfall erosion index (R) was calculated based on Bols's equation (Bols, 1978). The values for of K and LS factors were calculated based on the equation according to Wischmeier and Smith (1978). Values for C and P factors were based on the CP values published by Hammer (1980). The tolerable soil loss as computed by Hammer (1982), was also the basis of determining the magnitude of erosion from each land unit identified in the research site.

Results and Discussion

Agro-climatic and Meteorological Characteristics

When monthly rainfall is less than 60 mm, it is dry season while rainy season is characterized by rainfall more than 100 mm (Sandy, 1987). In the research site, the months from October to April is rainy season and May to September are the dry months. The mean annual rainfall is 2,568 mm.

Minimum and maximum temperatures were recorded at 14℃ and 24℃, respectively. Monthly evaporation was also found to be high in October and low in June with a daily mean of 3.2 mm. The magnitude of evaporation is significantly correlated with temperature. Monthly relative humidity recorded show that the highest occurred in March and the lowest in October with daily mean of 87.9%.

Topography and Slope Pattern

Areas with flat to undulating topography and having a slope of 0〜8% account for 25% (about 562 hectares) of the research area. However, areas with moderate to steep slopes

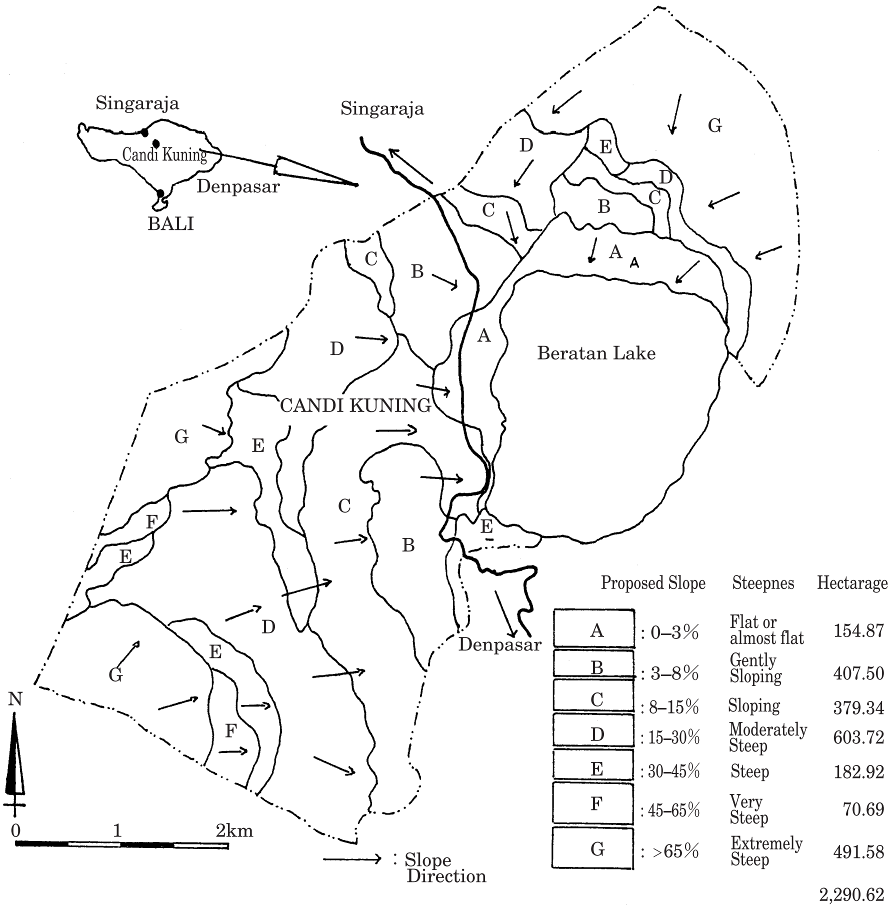

Fig. 3 Slope map of Candikuning, Tabanan, Bali, Indonesia

occupy 75% (about 1,728 hectares) of the total area. Steep lands are usually prone to erosion and cultivation could exacerbate the problem. The topographic and slope class maps of the research area are shown in Figs. 2 and 3, respectively.

Soil Characteristics

Tables 1 and 2 present the physical and chemical properties of the soil in the research area, respectively. Soil texture ranges from silty loam to loamy sand, although there is a considerable amount of sand present. The dominance of sand causes some elements, particularly nitrate nitrogen to decrease rapidly either by leaching or runoff. This explains the very low availability of nitrogen.

Other parameters analyzed to determine the fertility status in the area included CEC, base saturation and organic carbon content (Puslittanak, 1995). As the parent material of these soils is intermediary volcanic ash temporary deposited from surround volcanoes, they tend to have high nutrient content. The soil fertility status in the research area is presented in Table 3.

It was also found that the fertility of the soil in the lower slope is relatively higher compared to the middle and upper slopes. This is a result of nutrient deposition in the lower slopes from the upper slopes because of erosion. As consequence of advanced erosion, nutrient availability may drop in long-term.

Land Use

Candikuning village is dominated by forest

Table 1 Physical properties of the soil in the research area

Samples Codes	Characteristics	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Structure	Permeability (cm s^{-1})	Bulk density (g cm^{-3})
S1 (4)	Bukit Catu	0–30	85.8	2.8	1.4	Loamy Sand	Granular	1.61×10^{-3}	0.96
	(dry land (slope : 23%))	30–60	91.5	4.8	3.7	Sand	Granular	1.19×10^{-3}	0.91
S2 (3)	Bukit Catu	0–30	86.8	7.5	5.7	Loamy Sand	Granular	6.19×10^{-4}	0.79
	(dry land (15%))	30–60	61.5	36.8	1.7	Sandy Loam	Granular	3.17×10^{-4}	0.66
S3 (3)	Kembang Merta	0–30	55.8	30.1	14.1	Sandy Loam	Granular	3.47×10^{-4}	0.83
	(dry land (11%))	30–60	26.3	50.1	23.6	Silty Loam	Granular	6.11×10^{-4}	0.72
S4 (2)	Kembang Merta	0–30	34.9	55.2	4.9	Silty Loam	Granular	4.50×10^{-4}	0.84
	(dry land (8%))	30–60	54.7	30.8	14.5	Sandy Loam	Granular	1.27×10^{-3}	0.84
S5 (2)	Kembang Merta	0–30	65.7	16.3	18.0	Sandy Loam	Granular	8.25×10^{-4}	0.73
	(dry land (3%))	30–60	63.0	29.6	7.4	Sandy Loam	Granular	1.33×10^{-3}	0.76
S6 (8)	Forrest land (7%)	0–30	49.6	49.6	0.8	Sandy Loam	Granular	9.58×10^{-4}	0.72
		30–60	84.3	13.9	1.7	Loamy Sand	Granular	2.27×10^{-3}	0.70

Table 2 Chemical properties of the soil in the research area

Samples codes (Land unit)	Depth (cm)	pH (H_20)	Org. matter (%)	CEC (cmol/kg)	Base saturation (%)	Total-N (%)	Available-P (ppm)	Available-K (ppm)
S1 (4)	0–30	5.87	1.63	12.11	82.76	0.058	86.76	27.58
	30–60	6.29	0.85	12.80	88.13	0.015	31.59	33.29
S2 (3)	0–30	6.00	3.76	17.60	99.56	0.180	97.73	33.31
	30–60	6.38	3.01	16.74	94.74	0.123	12.13	24.79
S3 (3)	0–30	5.68	3.27	17.19	34.15	0.081	22.94	61.26
	30–60	5.28	2.66	19.55	46.52	0.064	10.87	87.43
S4 (2)	0–30	5.87	2.90	14.27	95.53	0.060	73.08	119.06
	30–60	6.12	1.73	22.44	31.68	0.031	9.02	149.51
S5 (2)	0–30	4.86	3.68	19.52	55.92	0.044	75.43	25.49
	30–60	5.46	2.53	14.49	89.56	0.061	54.60	31.64
S6 (8)	0–30	5.94	3.28	13.88	90.91	0.088	17.30	43.87
	30–60	6.18	2.50	20.32	96.84	0.067	7.91	27.88

Table 3 Soil fertility status in the research area

Samples codes (Land unit)	Location	Slopes (%)	Fertility status
S1 (4)	Bukit Catu	23	medium
S2 (3)	Bukit Catu	15	very high
S3 (3)	Kembang Merta	11	medium
S4 (2)	Kembang Merta	8	high
S5 (2)	Kembang Merta	3	very high
S6 (8)	Forrest land	7	high

with a total area of about 1,253 hectares, distributed in the surrounding part of Beratan Lake and in the western part of the village. The forest area includes parts of Mt. Pohen, Mt. Tapak and the Botanical Garden of Bedugul.

The major land use classifications in the village include forest, dry land crops, settlements and lake. Land uses patterns and their distribution is described in Fig. 4. Vegetable is the dominant dryland crop, which include cab-

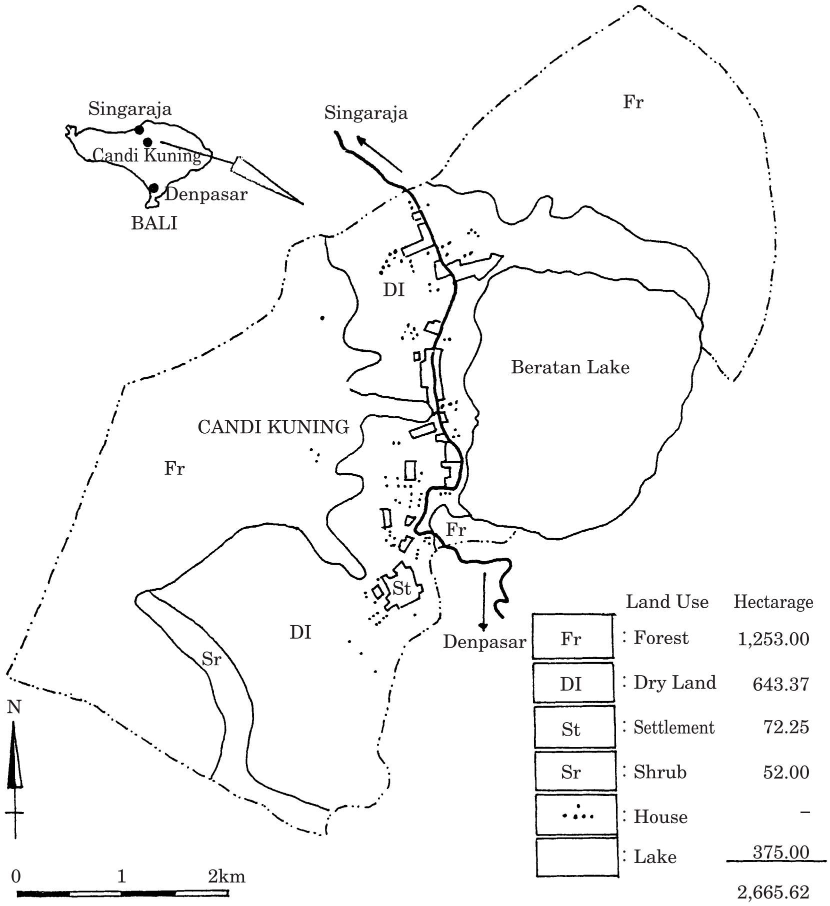

Fig. 4 Land use map of Candikuning, Tabanan, Bali, Indonesia

bage, potato, carrot, lettuce, garlic, celery and others. Corn, sweet potato and banana are also planted in the dry lands and consist of about 643 hectares.

Erosion

Values for the USLE equation factors as determined from the research site are presented in Table 4. Table 5 presents comparison between the actual level of erosion and the value of tolerable soil loss in the research area. Based on these calculation, predicted soil erosion in the research area was delineated in map as shown in Fig. 5.

It was found out that the soil erosivity was high during the months of October to March, which are within the rainy season. Soil erodibility was classified as moderate to very high. This is mainly due to the high percentage of very fine sand and silt and low clay content. As regards the slope length and steepness (LS) factor, the increase in length and steepness of slope results to higher LS values for the USLE.

The applied soil conservation measure in the dryland vegetable areas was bench terrace, although the quality of terraces in the lower slopes is better than those constructed in the upper slopes. This condition caused stability of the bench terrace riser in the upper slopes is lower than in the lower ones. Accordingly, the locations in the dryland vegetable crops with >15%～>30% slope, experience a severe to very severe erosion occurrence. Aside from the slope, low density of vegetation contributed to

Table 4 Values of the USLE components as determined in the research areas

Land unit	Erosivity (MJ mm ha^{-1} h^{-1} y^{-1}) (R)	Erodibility (t ha h MJ^{-1} ha^{-1} mm^{-1}) (EK)	Slope factor (ELS)	Cover and management factor (EC)	Conservation practices factor (EP)	Predicted soil erosion (t ha^{-1} y^{-1}) (A)	Level of soil erosion
1	21276	0.0173	0.23	0.400	0.15	5.08	very slight
2	21276	0.0410	1.40	0.400	0.15	73.27	moderate
3	21276	0.0262	1.98	0.400	0.15	66.22	moderate
4	21276	0.0181	5.50	0.400	0.35	296.52	severe
5	21276	0.0308	9.50	0.400	0.35	871.52	very severe
6	21276	0.0308	9.60	0.300	0.40	754.11	very severe
7	21276	0.0354	0.75	0.005	1.00	2.82	very slight
8	21276	0.0354	2.00	0.005	1.00	7.53	very slight
9	21276	0.0354	5.00	0.005	1.00	18.83	slight
10	21276	0.0354	8.50	0.005	1.00	32.01	slight
11	21276	0.0354	18.31	0.001	1.00	13.79	slight
12	21276	0.0354	33.32	0.001	1.00	25.10	slight

$A = R \cdot EK \cdot ELS \cdot EC \cdot EP$

Table 5 Comparison of the predicted soil erosion and tolerable soil loss in the research areas

Land unit	Soil depth (mm)	Depth factor (mm y^{-1})	Resource life (y)	Predicted soil erosion (t ha^{-1} y^{-1})	Tolerable soil loss (t ha^{-1} y)	Degree of erosion
1	1100	1.0	300	5.08	3.67	Very slight
2	1050	1.0	300	73.27	3.50	Moderate
3	1200	1.0	300	66.22	4.00	Moderate
4	1100	1.0	300	296.52	3.67	Severe
5	1150	1.0	300	871.52	3.83	Very severe
6	1050	1.0	300	754.11	3.50	Very severe
7	1200	1.0	300	2.82	4.00	Very slight
8	1100	1.0	300	7.53	3.67	Very slight
9	1050	1.0	300	18.83	3.50	Slight
10	950	1.0	300	32.01	3.17	Slight
11	1000	1.0	300	13.79	3.33	Slight
12	850	1.0	300	25.10	2.83	Slight

[Tolerable soil loss] = [Soil depth (mm)] × [Depth factor] / [Resource life (years)].

the higher rates of erosion.

On the other hand, the forestlands and dry vegetable crop areas with less than 3% slope have only slight erosion. Combination between intensive soil surface protection (by vegetation canopy), effective soil conservation measures and appropriate cropping pattern in the high risk erosion such as the dryland vegetable area, should be established to prevent soil erosion and maintain soil fertility as a prerequisite to achieve sustainable farming system in tropical volcanic highland.

Conclusion

Forest and dryland vegetable crops dominate the major land use in the research area. The main physiography in the area is volcanic, with rolling to mountainous landforms. The area has a moderate to steep slope. General soil fertility status ranges from medium to high

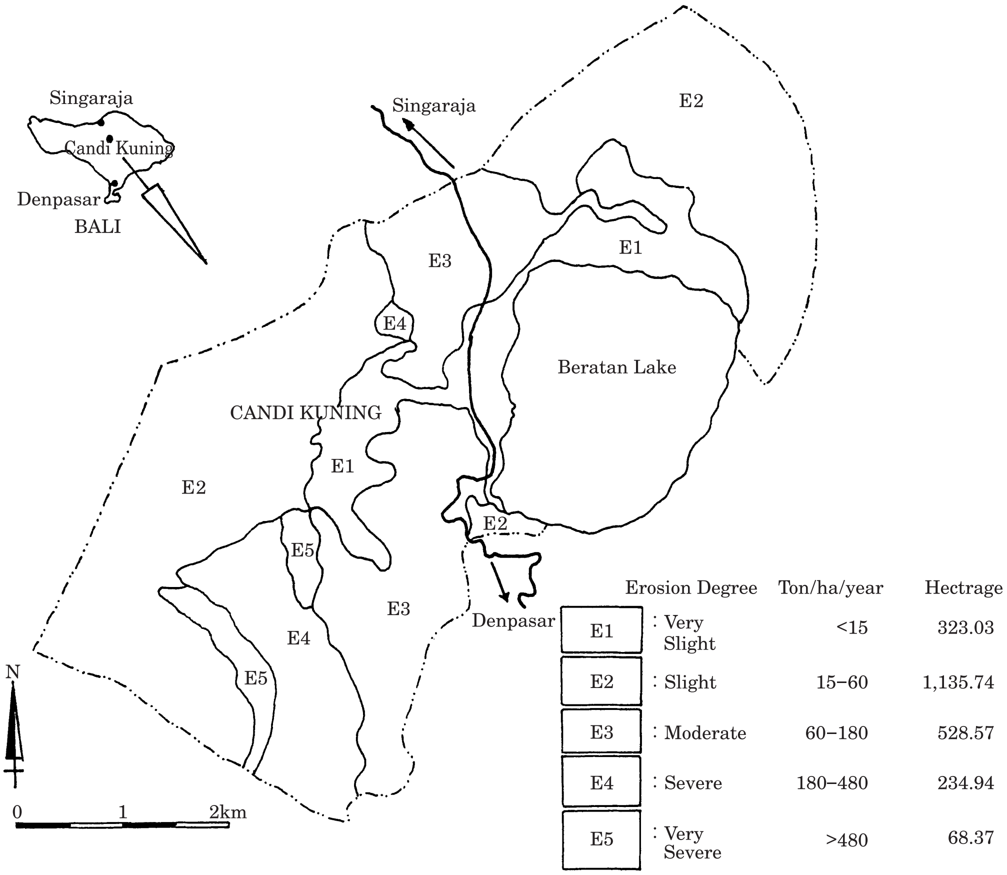

Fig. 5 Erosion map of Candikuning, Tabanan, Bali, Indonesia

due to high organic matter content and base saturation. Important limiting factor of soil fertility is low nitrogen. Soil texture is sandy and has low bulk density.

The erosion degree in the area ranges from very slight to very severe, depending on land status. Erosion occurred slightly in the forestland, but it was severe in the drylands with slope more than 15%. To achieve sustainable farming in the slope lands, effective conservation measures combined with soil surface protection and appropriate cropping pattern should be establish in the tropical volcanic highland.

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インドネシア・バリ島チャンディクニンの高標高傾斜地農業における土地特性と土壌侵食

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要　　旨

土壌侵食のような自然環境問題は，ある地域では畑地や高地農業システムに深刻な影響を与えている。本論は，火山灰土壌で覆われたインドネシア国バリ島の Candikuning 村で実地調査を行い，この地域の傾斜地農業に関連した土壌物理的特性と土壌侵食程度を検討したものである。

この地域は，標高 1,200～2,100 m にあり，上位に森林，中位から下位にかけて畑地（野菜）が広がっており，緩傾斜～急傾斜のカルデラ地形に立地している。この地域の主要土壌型は Andosols と Regosols であるにもかかわらず，案外肥沃レベルが高かった。森林地帯ではわずかに侵食が発生する程度であるが，斜度 15％以上の乾燥・低木地帯では厳しい侵食が起こっていた。

そのような状況のもとで適切な土壌・水保全対策を立案するにあたり，地域区分図，地形図，傾斜図，土地利用図，土壌侵食図などをまとめ上げ，画一的ではない，この地域の特性に応じた適切かつ維持可能な農業システムを確立する必要があることを論じた。

キーワード : 土壌侵食，傾斜地農業，高標高，バリ島，インドネシア

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