LAND MANAGEMENT FOR SUSTAINABLE AGRICULTURE IN NORTH COASTAL PLAIN, BALI [1]

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Abstract

Intensive farming system development will lead to trade-off between economic benefits in the short run and environmental problems, especially critical soil erosion in the long run. The excessive erosion has reduced soil quality, then caused rapid reduction in land productivity or even made the land unsuitable for agriculture. If agriculture is to become sustainable, land management must be considered as one of best management practices in farming system development. A research in Tembok Village, Buleleng Regency, Bali aims to assess land suitability, soil fertility, soil erosion and conservation, and soil nutrient management for irrigated mixed farming system in north coastal plain of Bali.

It is found that coastal area in the study area is classified into poor fertile soil due to the low level of cation exchangeable capacity and organic matter content. It is potentially categorized as marginal suitable (S3) for maize, cassava, groundnuts, sweet potato, melon, chili, banana, cashew, coconut, and palmyra palm; and suitable enough (S2) for mango, papaya and fodder grasses. The erosion level was very light by 2.036 t/ha/yr. This level has good relation with the erosion level by 2.04 t/ha/yr from laboratory experiment result by Sukartaatmadja et al. (2003) with similar characteristic of land and cow manure dosage requirement by 5 t/ha/yr. To improve soil fertility and to keep soil erosion not more than 2.036 t/ha/yr, the minimum 5 t/ha/yr of manure should be added into soil.

Key words: *land suitability, soil fertility, erosion, sustainable agriculture*

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1. Introduction

The vision of Indonesian's agricultural development in 2020 is to form a modern and an efficient agriculture, one of its characteristics is optimal and sustainable use of resources such as land, water, germ plasma, labor, capital, and technology (Kasryno *et al.*, 1997). According to FAO Council (Kwaschik *et al.*, 1996), sustainable agriculture; an integral part of sustainable development; is a farming system that conserves land, water, plant and animal's genetic resources, technically appropriate, economically viable, socially acceptable, and environmentally non-degrading.

The Sustainable Development of Irrigated Agriculture in Buleleng and Karangasem (SDIABKA) project in north coastal plain, Bali, attempted: (1) to install 15 groundwater irrigation systems which constructed under the previous project; and (2) to optimize groundwater used in the project area through rehabilitation and upgrading of additional nine groundwater irrigation systems (Project Management Unit, 2003). About 2,015 farmers were covered in the project. They, which organized in 39 tube well user groups, were introduced profitable mixed-farming practices and procedures for farming system development on approximately 703 ha effective area.

Coastal plain like in the SDIABKA project area is generally a region with poor fertile soil, high water losses through percolation, high evapotranspiration and run-off, and groundwater as being primary water source. The project area; approximately 5,300 ha, with 30 km long and varies in width between 1 and 3 km; lies in 12 villages in Buleleng and Karangasem regencies (Project Management Unit, 1995; 2003). The interface depth at one km from the sea is over 100 m for all project area and at 100 m from the sea is between 35 m and 50 m below sea level. The project is also supported by 13,500 ha catchment area (Project Management Unit, 1995).

Moreover, intensive farming system development will lead to trade-off between economic benefits in the short run and environmental damages, especially soil fertility degradation in the long run (Herianto, 2002). On one hand, the expansion of cultivated land produced severe erosion problems (Barbier *in* Small, 2003), on the other hand, unregulated farming practices have caused critical soil erosion (Saragih, 1989). The excessive erosion has reduced soil quality, then caused rapid reduction in land productivity or even made the land unsuitable for agriculture (Saragih, 1989; Lal *et al.*, 1990). These phenomena have adversely jeopardized agricultural production in the long run. It means that as environmental degradation increases, agriculture will eventually become unsustainable (Sugino and Hutagaol, 2004).

Based on the background above, this paper aims to assess land suitability, soil fertility, soil erosion and conservation, and soil nutrient management for irrigated mixed farming system in north coastal plain of Bali.

2. Material And Methods

2.1 Research Location

One of the 39 schemes under the SDIABKA project with well code TMB-59 in Tembok Village, Tejakula District, Buleleng Regency was chosen purposively for the following reasons: (1) new scheme, (2) supply quantity is 23.34 l/s, (3) effective area 23.02 ha, and (4) mixed farming system operated by 42 farmers.

2.2 Material and Equipment

Soil observation in TMB-59 needed a lot of material and equipment. The equipment covers: (1) augerlcore (Belgi type bore), (2) hoe and shovel, (3) gauge, (4) stiletto knife, (5) munsell soil color chart book, (6) pH electrode, (7) loupe, (8) handboard, (9) abney level, (10) binoculars, (11) compass, (12) altimeter, and (13) topographic map of TMB-59. Then, the materials are: (1) clean water in bottle, (2) plastic bag for soil samples, (3) label paper for coding on the soil samples, (4) questionnaire in database format to record the soil characteristics and morphology systematically, from soil profile and around the land, and (5) key book of soil taxonomy.

2.3 Research Implementation

Soil observation was conducted by: (1) drilling, and (2) minipit (0.5 m x 0.5 m x

0.5 m). Soil classification and land evaluation based on soil samples were taken representatively at three-observation point in TMB-59. Soil samples were collected from two layers of each observation point at the amount of 0.5 – 1.0 kg. Besides that, it was taken as soil samples for special purposes i.e. (1) undisturbed soil samples by ring from some layers (0 – 0.27 m, 0.27 - 0.44 m, and 0.44 – 1.05 m) to obtain bulk density, permeability, electric conductivity; (2) composite soil samples for fertility soil analysis which were collected from some observation point by drilling were then mixed to become homogeneous soil samples. Then, all soil samples would be analyzed in laboratorium.

2.4 Method of Analysis

Land suitability and soil fertility assessment were based on observation and analysis result from Soil Laboratory of Udayana University, Denpasar. The analysis result was then fitted in well with the specific parameters for crop requirements by Sys *et al.* (1993) and the criteria of land suitability for agricultural commodities by Djaenudin *et al.* (2000).

The most widely used method of soil loss prediction by conservationists in the United States is the Universal Soil Loss Equation (USLE) (Mitchell and Bubenzer, 1980: 21): A = (0.224)RKLSCP where A = the soil loss (kg/m^2/yr); R = the rainfall erosivity factor; K = the soil erodibility factor; L = the slope length factor (m); S = the slope gradient factor (%); C = the cropping management factor; and P = the erosion control practice factor. The rainfall erosivity factor (R) is calculated by Bollinne formulae, R = 159.56 + 0.27 P where P = rainfall in mm/yr (Darmawan, 2001). The soil erodibility factor (K) is calculated by Wischmeier and Smith equation (Nuarsa, 1991), $100\ K = 1.292\ [2.1M^{1.14}(10^{-4})(12 - a) + 3.25(b-2) + 2.51\ (c-3)]$ where M is particle size of erodible soil = (% silt + % powder sand) (100- % clay), a = organic matter content of soil (%), b = the texture class, and c = permeability class (cm/hour). The slope length and slope gradient are represented as L and S, respectively, however, they are often evaluated as a single topographic factor $(LS) = \sqrt{L}(0.00138S^2 + 0.00965S + 0.0138)$. Estimation of the cropping management factor (C) and the erosion control practice factor (P) were based on field observation and the CP value table was assesed in Pusat Penelitian Tanah Bogor (Nuarsa, 1991).

Conservation planning needs the recommended value for maximum soil loss tolerance (Edp) in mm/yr or t/ha/yr. In accordance with Hammer (*in* Nuarsa, 1991), soil loss tolerance is calculated by equation, Edp = (soil depth x depth factor) ÷ useful life of soil.

The result of erosion prediction was compared to the recommended value for maximum soil loss tolerance. If the erosion level is more than Edp, the conservation planning and implementation will be needed by determining C and/or P value to generate the expected erosion less or equal to the Edp. However, if the erosion level is less than or equal to Edp, the action will be soil maintaining so that this would not make new damage possible.

3. Result And Discussion

3.1 Genesis and Soil Classification

All factors of soil maker, main materials, relief, organism, and time have great influence in soil formation and development processes. But, the main materials and organism have dominant share compared to the other factors.

The main material has considerable influence to the soil characteristics. TMB-59 has soil texture looking like sediment of volcanic sand, sandy loam. The reason for the phenomenon was a slowly decaying process of soil due to little annual rainfall (1477 mm/year) and distribution of monthly rainfall, which was not steady in a year (minimum 0 mm/month and maximum 397 mm/month) (BMG Wilayah III Denpasar, 2006). Besides that, the existence of organism, i.e. (1) a few of vegetation have a little organic matter share to the soil, and (2) human share is not optimal, this is shown by non intensive land management and a few animal population sharing organic matter to the soil.

Due to climate type E (Schmidt and Ferguson *in* Balai Penelitian Tanah, 2004), and land preparation was not being intensively done, then the process of soil formation and development were very slow, so that the soil in TMB-59 was categorized as low developing soil (Inceptisol order). In suborder category, Inceptisol soil is categorized as Usteps because it is assumed to have the Ustik regime according to Badan Penelitian Tanah (2004). Ustik regime is a regime with limited soil water content but available at its condition suitable for plant growing. Furthermore, in great group, soil in TMB-59 was classified into Plagepts based on soil classification and characteristics (Djaenudin *et al*, 2000), because its actually has soil depth more than 50 cm, texture class of rather hard (ak), C-organic more than or equal to 0.6 percent, pH more than 0.5, and saturation base more than 50 percent.

3.2 Land Suitability

According to Djaenudin *et al.* (2000), land evaluation is an estimation process of class of land suitability and potential land for special land use: agriculture and non agriculture. Potential land for agricultural development is basically determined by appropriateness between the physical characteristic and crops requirement. Suitability between physical characteristic of the land and the commodities that are evaluated give information that commodities are potentially developed in the land. These mean that special land use with some consideration including needed inputs can generate expected outputs.

Land suitability is appropriateness of a land for special use such as irrigated agriculture, fishpond, seasonal or perennial crops (Djaenudin *et al.*, 2000). The result of land suitability assessment for food crops, horticulture, and agro forestry is presented in Table 1.

Table 1. The result of land suitability assessment for some commodities

Type of Commodity		Location (in TMB-59)		
		Upland	Middle	Lowland
1. Maize	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
2. Cassava	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
3. Groundnuts	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
4. Sweet potato	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
5. Melon	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
6. Chili	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
7. Mango	A	S2 rc nr eh	S2 rc nr	S2 rc nr
	P	S2 rc	S2 rc	S2 rc
8. Papaya	A	S2 rc nr eh	S2 rc nr	S2 rc nr
	P	S2 rc	S2 rc	S2 rc
9. Banana	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
10. Cashew	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
11. Coconut	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
12. Palmyra palm	A	S3 rc	S3 rc	S3 rc
	P	S3 rc	S3 rc	S3 rc
13. Fodder grass	A	S2 wa nr eh	S2 wa nr	S2 wa nr
	P	S2 wa	S2 wa	S2 wa

Notes: A = actual, P = potential, S2 = moderately suitable, S3 = marginal suitable, rc = root condition, nr = nutrient retention, eh = erosion hazard, and wa = water available.

Based on land suitability assessment for maize, cassava, groundnuts, sweet potato, melon, chili, banana, cashew, cacao, coconut, and palmyra palm, the farmland in TMB-59 is actually classifiable into marginal suitable with root condition as a major constraint. For mango and papaya, the farmland in TMB-59 is categorizable into moderately suitable with root condition, nutrient retention, and erosion hazard as major constraints, while for fodder grass, the farmland is categorized as moderately suitable with water available, nutrient retention, and erosion hazard as major constraints.

Root condition component that affects land suitability is soil texture (sandy loam). The effective nutrient retention is low level of cation exchangeable capacity (CEC) (between 5 and 16 me/100 g of soil) while the influencing erosion hazard factor is slope gradient rather than the slope length (Baver; Schwab *et al.* in Nuarsa, 1991).

Utomo (*in* Nuarsa, 1991) claims that the dominant influence of slope gradient to soil erosion is possible due to the fact that slope gradient affects the speed and volume of surface movement. The bigger percentage of slope gradient the fewer the available time for infiltration. Then, the faster the runoff the bigger the stream volume and erosion are. The slope length only influences volume of runoff so that it also influences the possibility of erosion.

Based on the soil evaluation, some type of commodities can be developed in farmland of TMB-59 with major constraints consideration. The soil texture cannot improve hence the land suitability class is still potentially categorized into S3 for maize, cassava, groundnuts, sweet potato, melon, chili, banana, cashew, coconut, and palmyra palm, and S2 for mango, papaya, and fodder grass. Even though the soil texture cannot improve in relatively short time, some soil characteristics that are interconnected with soil texture can be improved such as soil water content and its ability to hold nutrient. To increase land productivity, it can be done by addition of organic matter that will improve the soil ability to hold water and nutrients. The addition of organic matter can also increase CEC of soil so that the effort will also anticipate the nutrient retention factor. Intensive cropping system such as utilization of seed with best quality, land preparation, cropping pattern, irrigation, fertilization, and pest management must be applied to increase land productivity, and also to maintain of land fertility. Furthermore, erosion hazard especially slope gradient, can be anticipated by terraces and increasing the closeness of plants.

3.3 Land Fertility

The result of land fertility assessment, which is presented in Table 2, shows that farmland in TMB-59 is actually categorized as poor fertile soil. Some components that was generated is the low level of CEC and organic matter content. Improving the fertility status can be done by addition of organic fertilizer up to the middle or high level. Application of organic matter will be better by utilizing animal manure or other source such as compost.

Table 2. The result analysis of soil fertility status

Soil Sample	CEC	Saturation-based (SB)	P_2O_5	K_2O	C-organic	Soil Fertility Status
1	11.23 (R)	177.78 (T)	43.87 (T)	634.42 (T)	1.22 (R)	R
2	10.58 (R)	188.23 (T)	21.73 (S)	633.25 (T)	1.62 (R)	R
3	7.78 (R)	178.95 (T)	233.74 (T)	367.51 (T)	1.60 (R)	R
4	7.21 (R)	160.01 (T)	8.44 (R)	197.55 (T)	1.20 (R)	R
5	8.99 (R)	172.72 (T)	131.22 (T)	195.81 (T)	1.99 (R)	R
6	8.29 (R)	189.99 (T)	27.31 (S)	458.89 (T)	0.81 (R)	R

Notes: T = high, S = middle, R = poor

3.4 Land Conservation

Solution of the USLE (Mitchell and Bubenzer, 1980) provided soil loss in the amount of 3.01, 1.76, and 1.34 tons/ha/year in the up-land, middle, and lowland of TMB-59, respectively (Table 3).

Table 3. Erosion prediction and erosion level

Location in TMB-59	Erosivity (R) [a]	Erodibility (K) [b]	LS Factor [c]	CP Factor	Soil Loss (ton/ha/year)	Erosion Level [d]
Up-land	558.35	0.1866	1.6147 L=7; S=13	0.08 [e]	3.01	Very light
Middle	558.35	0.1806	0.9744 L=8; S=6	0.08	1.76	Very light
Low-land	558.35	0.2525	1.0608 L=12; S=4	0.04 [f]	1.34	Very light

Notes: a. The rainfall erosivity factor based on Bollinne formulae, R = 159.56 + 0.27P (Darmawan, 2001) where P=rainfall 1477 mm/year (BMG Wilayah III Denpasar, 2006);
b. Soil erodibility factor based on Wischmeier & Smith equation (Nuarsa, 1991) (**Table 4**)
c. LS factor based on Wischmeier and Smith equation (Nuarsa, 1991); L < 50 m is very short (FAO *in* Balai Penelitian Tanah Deptan, 2004); 0% <S< 8% is flat, 8% <S< 15% is sloping
d. Erosion level classification according to Greenland and Lal (*in* Nuarsa, 1991)
e. Multiple cropping, middle densities, and traditional terraces (Nuarsa, 1991)
f. Multiple cropping, high densities, and traditional terraces (Nuarsa, 1991)

Table 4. Soil erodibility factor, K

Location in TMB-59	Particle size of soil (M)	Organic matter content (a)	Soil structure class (b)	Perme-ability class (c)	100 K	K	Erodibility Class *)
Up-land	2824.02	1.22	2 (sg)	1 (q)	18.66	0.1866	Low
Middle	2520.65	1.60	2 (sg)	2 (rq)	18.06	0.1806	Low
Low-land	2684.99	1.99	2 (sg)	4 (rt)	25.25	0.2525	Middle

Notes: *) Soil erodibility class by Dangler and El-Swaify (*in* Nuarsa, 1991); sg = smooth granular, rt = rather tardy, rq = rather quickly, and q = quickly (Utomo *in* Nuarsa, 1991).

Estimation of the cropping management factor (C) and the erosion control practice factor (P) based on field observation, and then it was compared with the CP value table by Pusat Penelitian Tanah Bogor (*in* Nuarsa, 1991). Soil loss tolerance is the maximum rate of soil erosion that permits a high level of productivity to be sustained (Mitchell and Bubenzer, 1980). In TMB-59, the soil loss was less than the soil loss tolerance (Table 5). This means that no action for land conservation was made, but it needs land maintenance so that land productivity can be sustained.

Table 5. Soil loss tolerance in TMB-59

Location	Soil depth (mm)	Depth factor	Useful life of soil (year)	Edp (mm/year)	Bulk Density (gr/cm^3)	Edp (ton/ha/year)
Up-land	1080	1.00	300	3.60	1.104	39.74
Middle	800	1.00	300	2.67	1.098	29.32
Low-land	1100	1.00	300	3.67	1.187	43.56

3.5 Soil Nutrient Management

Nutrient cycling is theoretically based on the balance of nutrient in soil ecosystem, but in this research, soil nutrient management is only based on crop manure requirement in SDIABKA project area. The manure requirement for perenial, semi perenial and seasonal crops in TMB-59 is presented in Table 6.

The manure requirement for some commodities in 23.352 ha effective area in TMB-59 is approximately 308.66 ton per year (Table 6), but available animal manure produced annually is approximately 202.74 ton (Table 7). It means that animal manure availability is deficit 105.92 ton per year. The amount can be achieved by addition of 58 units of cattle.

Table 6. Crop manure requirement for some commodities in TMB-59

	Crop Number	Manure Requirement (ton/year) *)

Mango	1082 trees	43.28
Coconut	739 trees	29.20
Cashew	336 trees	13.44
Banana	4,882 trees (31,962 m^2)	97.46
Papaya	513 trees (5,109 m^2)	30.78
Melon	2,180 m^2	6.54
Sweet potato	22,700 m^2	45.40
Chili	800 m^2	1.60
Fodder grasses	4,647 m^2	16.26
Maize	17,600 m^2	17.60
Maize + Groundnuts	3,000 m^2	3.00
Maize + Cassava	4,100 m^2	4.10
Total	233,520 m^2	308.66

*) Based on the result of trial plot in SDIABKA project area.

Table 7. Existing animal population and potential manure produced annually in TMB-59

	Livestock Number (unit)	Potential Manure Production (ton/year) *)
Cattle	94	171.55
Pig	120	25.23
Goat	17	3.09
Chicken	358	2.87
Total		202.74

*) Based on USDA data (*in* Logan, 1990)

4. Conclution And Recommendation

The soil in the study area is mostly inceptisol order with soil depth more than 50 cm, sandy loam, and rather hard texture class, C-organic less than 2 percent, pH more than 0.5, and saturation base more than 50 percent. It is actually classified into poor fertile soil due to the low level of cation exchangeable capacity (CEC, lied in interval 5 and 16 me/100 gram of soil) and organic matter content. Therefore, it is potentially categorized as marginal suitable (S3) for maize, cassava, groundnuts, sweet potato, melon, chili, banana, cashew, coconut, and palmyra palm, and moderately suitable (S2) for mango, papaya and fodder grasses.

The average length and gradient slopes in the area were 9 meters and 8 percent, respectively, with soil erosion level was categorized as very light by 2.036 tons/ha/year. The soil loss was less than the average soil loss tolerance by 37.54 t/ha/yr. This level has good relation with the erosion level by 2.04 tons/ha/year from laboratory experiment result with gradient slope mean of 9 percent and cow manure dosage by 5 tons/ha/year (Sukartaatmadja *et al.*, 2003).

To increase the soil fertility and land productivity and to keep soil erosion not more than 2.036 t/ha/yr, it can be done by addition of organic matter by minimum 5 t/ha/yr of manure. There was no action for land conservation due to the fact that soil erosion in TMB-59 was less than the soil loss tolerance, but it needs land maintenance such as addition of organic matter to protect soil against erosion to some extent, so land productivity can be sustained.

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