A land use planning recommendation for the Sumani watershed, West Sumatera, Indonesia.

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ABSTRACT In the present study, we provide a land use planning recommendation for land conservation and agro-economical production for the Sumani watershed in West Sumatra, Indonesia, where intensive agriculture has long been practiced. We based our land conservation management recommendations on soil erosion rates using the Universal Soil Loss Equation (*USLE*) determined in our previous paper (Aflizar et al. 2010). Our land use planning vision is to maintain current land use practices as much as possible. In sites where the soil erosion rate remains less than the tolerable erosion rate (TER) (14 Mg ha^{-1} y^{-1}; a rate set by the Indonesian government) land use was not altered. When soil erosion rates exceeded the TER, we selected a new land use with a smaller *CP*-factor than the former land practice to reduce soil erosion rates. The recommended land use planning resulted in a 16.1% change distributed as follows: vegetable gardens with terracing (10%), vegetable gardens with contour cropping (1.8%) and sawah (4.3%). The changes made in the recommended land use plans could reduce soil erosion rates by 88%, a reduction from 58.9 to 7.1 Mg ha^{-1} y^{-1}, with a total profit loss in agricultural production of only 3.9% in the Sumani watershed.

Key words: recommended land use, soil erosion, *USLE*

INTRODUCTION

The most destructive attribute of soils in Indonesia is soil erosion caused by heavy rain coupled with deforestation for expansion of agricultural fields necessary to meet the country's increasing demands for food. Soil erosion rates of 6-12 Mg $ha^{-1}y^{-1}$ on agricultural lands caused economic loss of US$ 340-406 million in Indonesia in 1989, which was responsible for nearly 80% of the decline in agricultural productivity (World Bank 1989). In recent years, demand for agricultural products has further increased due to population growth (Sarainsong et al. 2007). Accelerated deforestation and land use changes without concern for soil conservation has become a serious problem in Indonesia. Different levels of society have stressed the need for better land and watershed management planning to achieve sustainable agriculture and maintain economic productivity, while controlling soil erosion. However, prior to our research, the work to draft such a plan had yet to be conducted in Indonesia.

The Sumani watershed is the main rice production area in West Sumatra. The region has faced rapid land use change from forest to agricultural fields and a consequent increase in the rate of soil erosion. The average soil erosion rate in the watershed, estimated by the Universal Soil Loss Equation (*USLE*), increased from 43.13 Mg $ha^{-1}y^{-1}$ in 1992 to 58.91 Mg $ha^{-1}y^{-1}$ in 2002, coincident with changes in land use patterns (Aflizar et al. 2010). The soil erosion rate exceeded the tolerable erosion rate (TER) set for Indonesia, i.e. 14 Mg $ha^{-1}y^{-1}$ for 52% of the watershed land area.

Farmers in the Sumani watershed recognized that soil erosion was causing serious damage to their agricultural lands. Farmers were willing to implement soil conservation practices if they were trained and provided financial assistance. Consequently, efforts to integrate soil and water conservation practices in agricultural fields within watersheds were initiated by the Indonesian government through a program to local governments. This program is known as the National Movement for Forest and Land Rehabilitation (GN-RHL/GERHAN) (Watershed Management Agency, 2007). The details can be seen in Regionaldua (2007). However, due to demands by farmers and the soil conservation practices deemed suitable by the government, the program has not progressed in Indonesia due to the lack of reliable data on watershed soil erosion and planning strategies for improved watershed management. In a previous study (Aflizar et al. 2010), we evaluated soil erosion in the Sumani watershed, which is representative of a typical agricultural watershed in Indonesia i.e. the Sumani watershed. Based on the results of this work, in the present study we recommended a land use pattern for the watershed by modifying the land use types to reduce soil erosion to a value less than the TER, while maintaining agro-economical production in the watershed. This is the first case study addressing recommended land use planning based directly on soil erosion and agro-economic status at the watershed scale in Indonesia. Our aim is to provide local farmers and government agencies a realistic means to design a soil conservation plan and to implement it in Indonesia.

MATERIALS AND METHODS

Study area

The Sumani watershed occupies 58330 ha and is located in Solok regency (latitude 0°36′08″ to 1°44′08″S, longitude 100°24′11″- 101°15′438″E) approximately 50 km east of Padang City in West Sumatra, Indonesia (Fig. 1). The watershed outlet is Lake Singkarak. Average annual precipitation ranges from 1669 to 3230 mm, and the watershed occupies an elevation from 300 m to 2500 m above sea level (asl) (Farida et al. 2005). Sumani watershed (SW) consists of five subwatershed that is Sumani (S1), Lembang (S2), Gawan (S3), Aripan (S4) and Imang (S5). It is situated in a humid tropical zone. The Sumani watershed exhibits a variety of land uses, including primary forests, mixed gardens, vegetable gardens, sawah, abandoned agricultural fields and settlements. The term sawah refers to a levelled and bounded rice field with an inlet and outlet for irrigation and drainage (Wakatsuki et al. 1998). Mixed gardens are characterized by agricultural fields with perennial tree crops such as rubber, c`innamon, coffee, coconuts, and cloves planted with annual crops, and produce an average of 103, 101, 61, 21 and five Mg y^{-1}, respectively (Solok Statistical Agency, 2002). Sawo and avocado production were not recorded. In vegetable gardens, farmers primarily cultivate sweet potatoes (*Ipomoea batatas* L.),

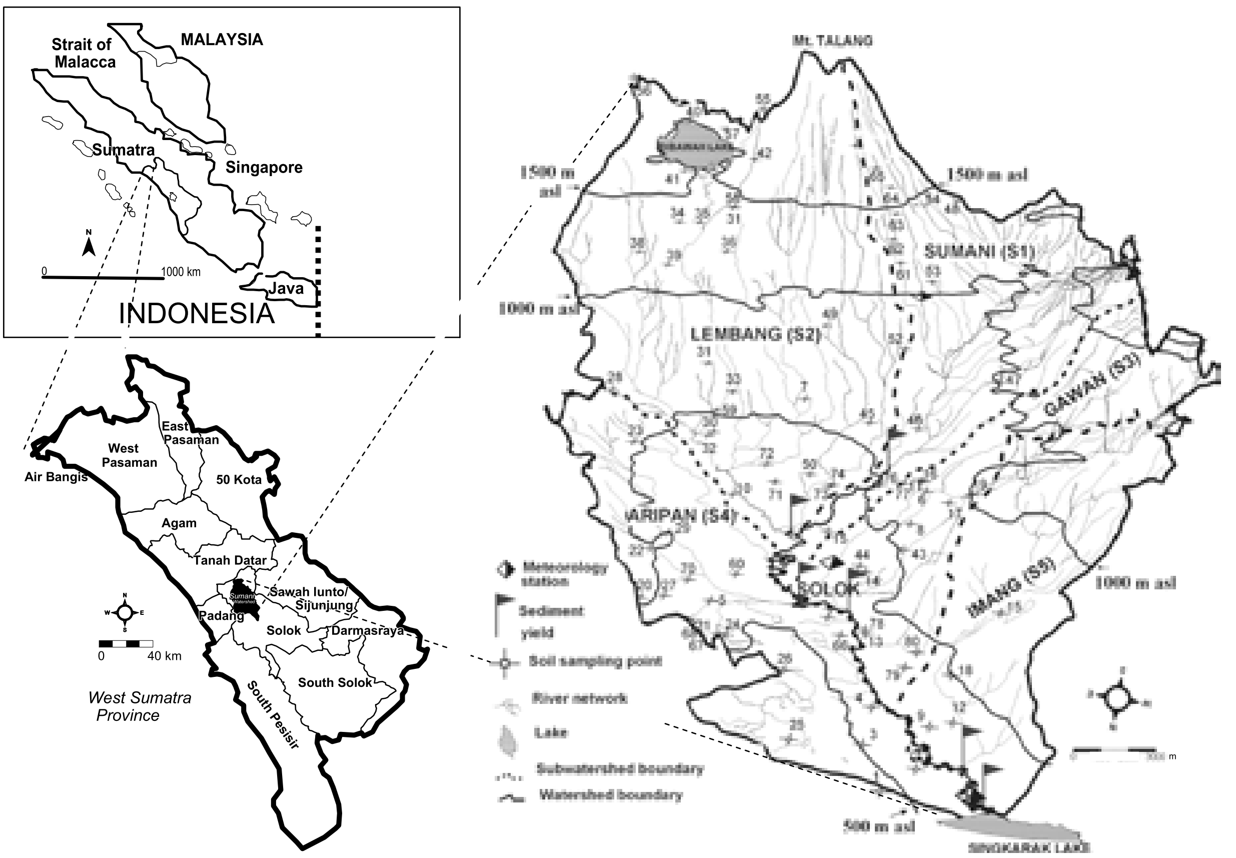

Fig. 1. Study site and distribution of soil sampling points sites in Sumani watershed, West Sumatra, coordinates bases on UTM coordinate system WGS 84 Zone 47 Southern Hemispire.

onions, tomatoes, chillies, corn (*Zea mays* L.) and soybeans (*Glycine max* L.) with average production of 9487, 3565, 1025, 783, 699 and 134 Mg y^{-1}, respectively (Solok Statistical Agency 2001). For detailed descriptions of the study site see Aflizar et al. (2010).

Soil erosion rate estimates in the watershed

In our previous paper (Aflizar et al. 2010), we estimated soil erosion rates in the Sumani watershed using *USLE* (Wischmeier and Smith 1978). In the *USLE* model, mean annual soil loss is expressed as a function of six erosion factors

$$E = R \times K \times L \times S \times C \times P \quad (1)$$

where E is estimated soil loss in Mg $ha^{-1}y^{-1}$; R is rainfall erosivity (dimensionless); K is inherent soil erodibility (dimensionless); L is slope length factor (dimensionless); S is slope factor (dimensionless); C is crop cover factor (dimensionless); and P is a factor that accounts for the effects of soil conservation practices (dimensionless).

The watershed was divided into 39312 grids sized 125 m x 125 m and basic data were allocated or estimated in each grid. Data were obtained by map reading, assessing a Landsat image for land use types and altitude, and use of the kriging method (Golden software 2002) for precipitation and soil properties. Based on these data, each *USLE* factor was calculated in each grid unit. Among the above factors, *C*- and *P*-factors can be field modified to improve soil erosion and agro-economical conditions in the watershed.

Economic feasibility analysis

Economic feasibility for different land use types in the watershed was evaluated from its cost-benefit ratio, which was calculated as

$$BC \text{ ratio} = \frac{R - C}{C} \quad (2)$$

where R is revenue, which is calculated as production (kg) x price (US$ kg^{-1}) and C is cost (US$). BC ratio is shown as basic data to assess the efficiency of cost investment against the benefit gained from each different agricultural product. The BC ratio can be used as a guideline (ranging from 2.6-10.3) to prevent any loss of profit to farmers at each subsequent harvest due to large production costs (Choudhury et al. 1995, Slaney et al. 2010). In order to calculate these parameters, data on costs of labor, fertilizer, pesticide, seed, production and price of agricultural products were derived from a detailed social economic survey report form the Solok Statistical Agency in 2002 and Istijono (2006), the most recent available data during the study period. Because cost and revenue varied in the watershed, we summarized the results at sub-watershed levels, where varied land uses were distributed

Table 1. Result of the economic feasibility analyses in the Sumani watershed.

Land utilization type	Range of Soil Erosion Rate (Mg $ha^{-1}y^{-1}$)	Cost	Revenue (Production x Price)	Benefit	Benefit-Cost Ratio
		(US$ $ha^{-1}y^{-1}$)			
Sawah					
Sawah at S1	0.010 – 6.32	183.76	1152.35	968.58	5.27
Sawah at S2	0.004 – 13.21	208.24	1124.22	915.98	4.40
Sawah at S3	0.003 – 13.18	265.18	1253.60	988.42	3.73
Sawah at S4	0.003 – 0.48	363.76	1339.50	975.73	2.68
Average	*1.0*	*255.24*	*1217.42*	*962.18*	*3.77*
Vegetable gardens					
Pepper at S2 (*Capsicum annum*)	0.386 – 893.0	1482.35	5269.80	3787.45	2.56
Tomato at S2 (*Solonum lycopersicum*)	0.386 – 893.0	1065.88	7617.06	6551.18	6.15
Radish at S2 (*Raphanus sativus* L.)	0.386 – 893.0	373.13	1058.82	685.69	1.84
Red onion at S2 (*Allium ascalonicum* L.)	0.386 – 893.0	2140.71	7058.82	4918.12	2.30
Mixed croping at S4	0.144 – 751.0	562.12	3011.76	2449.65	4.36
Mixed croping at S5	0.145 – 628.0	684.24	2964.71	2280.47	3.33
Average	*132.3*	*1051.40*	*4496.83*	*3445.43*	*3.28*
Mixed gardens					
Duku[a] at S1 (*Langsium domesticum*)	0.152 – 213.0	174.12	774.12	600.00	3.45
Duku at S2 (*Langsium domesticum*)	1.928 – 348.0	204.71	804.71	600.00	2.93
Coconut at S3 (*Cocos nucifera*)	0.457 – 523.0	245.65	1304.47	1058.82	4.31
Coconut at S5 (*Cocos nucifera*)	61.457 – 556.0	245.65	1304.47	1058.82	4.31
Average	*66.9*	*217.53*	*1046.94*	*829.41*	*3.81*

S1= Sumani, S2= Lembang, S3= Gawan, S4= Aripan, S5= Imang sub-watershed, SW= Sumani watershed

[a] A common Indonesian local fruit.

(Table 1). Land use types with no cost and revenue such as forests, grasses, *alang-alang* (land dominated by *Imperata cylindrica* [Poaceae]) and shrub lands were omitted from the analyses. The average benefit values for land use of sawah and vegetable and mixed gardens were calculated as representative values to estimate and compare the total profit of agricultural production in the entire watershed currently and for the recommended land use.

Recommended land use planning

The *USLE* grid factor values were used to establish the spatial distribution of soil erosion rates under present farming practices in the Sumani watershed (Aflizar et al. 2010).

To establish a recommended land use planning protocol, we followed the procedures depicted in Figure 2. The analyses were conducted in each grid unit. In grids with soil erosion rates less than the TER (i.e. 14 Mg ha^{-1}

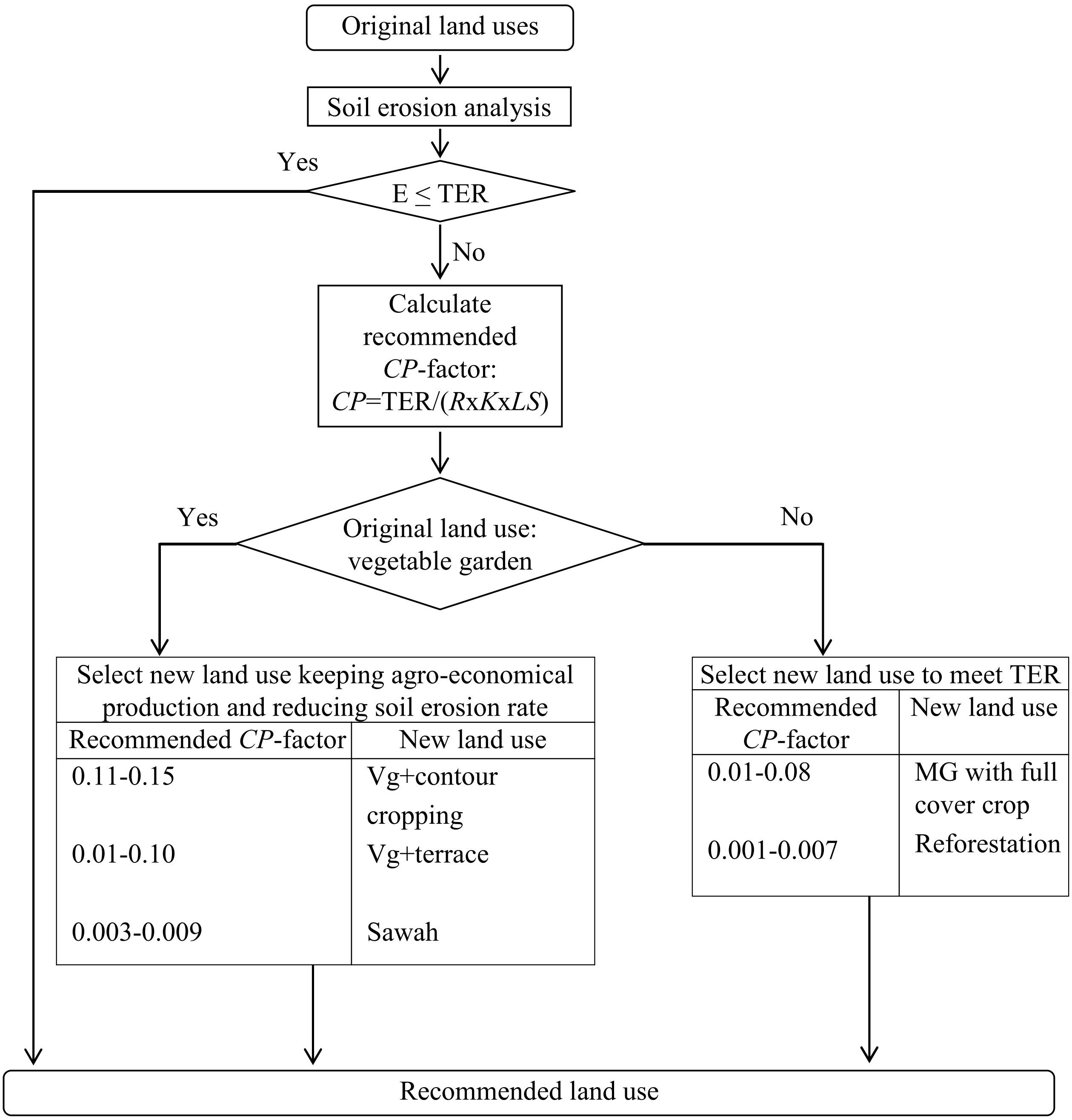

Fig. 2. Planning process model: E, Estimated soil erosion, TER, Soil loss tolerance for economic planning (14 Mg ha^{-1}y^{-1}), *CP*-factor: crop factor x protection factor of *USLE*, Vg: Vegetable garden, MG: Mixed garden.

y^{-1}) the land use type was maintained in the recommended land use planning. In the case study, all grids with forest, sawah and tea land uses exhibited soil erosion rates less than the TER, and therefore land use was unchanged. When the grid soil erosion rate exceeded the TER, we calculated *CP*-factors to meet the TER by the formula "recommended CP = TER / (R x K x LS)" for the respective grids. We subsequently selected a new land use from the candidates of suitable land uses. We separated the planning process (Fig. 2) for vegetable gardens, and mixed gardens and bush, because the latter is comprised of grasses, *alang-alang* (land dominated by *Imperata cylindrica* [Poaceae]) and shrub lands. Vegetable gardens generate the highest agro-economical benefit among land uses (Table 1), therefore we attempted to maintain vegetable garden land use by applying conservation practices, including contour cropping and terracing to reduce soil erosion rates. In the case where the recommended *CP*-factor was less than 0.008, we changed the land use to sawah. For mixed garden and bush land uses, full cover crop or reforestation were applied depending on the recommended *CP*-factors. In addition to the planning processes depicted in Figure 2, for the settlement grids located in steep slope areas that exhibited soil erosion rates exceeding the TER, soil conservation measures included home gardens with fruit trees and terracing to reduce soil erosion to acceptable levels (Table 2). The recommended land use change processes resulted in 58330 ha of the Sumani watershed modified to reduce soil erosion rates below the TER. Change in land usage are summarized in Table 2. The cost to apply soil conservation measures was not included in the calculation of benefit in the recommended land use shown in Table 2, as we expect the National Movement for Forest and Land Rehabilitation (GN-RHL/GERHAN) (Watershed Management Agency 2007) will support the costs to implement the measures.

In addition, we provided a simple simulation to evaluate the effects of applying a specific land use type to reduce soil erosion. We took an area with a soil erosion rate exceeding the TER under the present land use condition and converted it into a single land use type which possesses relatively low *CP-factors* (Fig. 3). Furthermore, areas with the soil erosion rates less than the TER were unchanged from the original land use type. Although this is not realistic planning, we addressed the effects of this type of approach.

Table 2. Change in land uses in the recommended land use planning.

	Present land use	Recommended land use
Soil erosion rate		
Average (Mg $ha^{-1} y^{-1}$)	58.9	7.1
Range (Mg $ha^{-1} y^{-1}$)	(0.001-1423.0)	(0.001-59.0)
Land use pattern (%)		
Forest	15.9	19.8
Sawah	23.3	27.6
Vegetable garden without conservation practices	24.9	5.6
Vegetable + terrace	0.0	10.0
Vegetable + contour cropping	0.0	1.8
Mixed garden	12.2	19.0
Grass	0.5	0.0
Alang-alang (*Imperata cylindrica)*	2.0	0.0
Shrub	3.7	0.0
Settlement	11.5	7.8
Settlement + home garden + terrace	0.0	3.7
Coconut	2.0	0.7
Tea	0.1	0.1
Water body	3.9	3.9
Total	100.0	100.0
Benefit from agricultural production (US \$ million y^{-1})	66.85	64.26

US $ 1 equivalent to about Rp 8500 at the period of the study

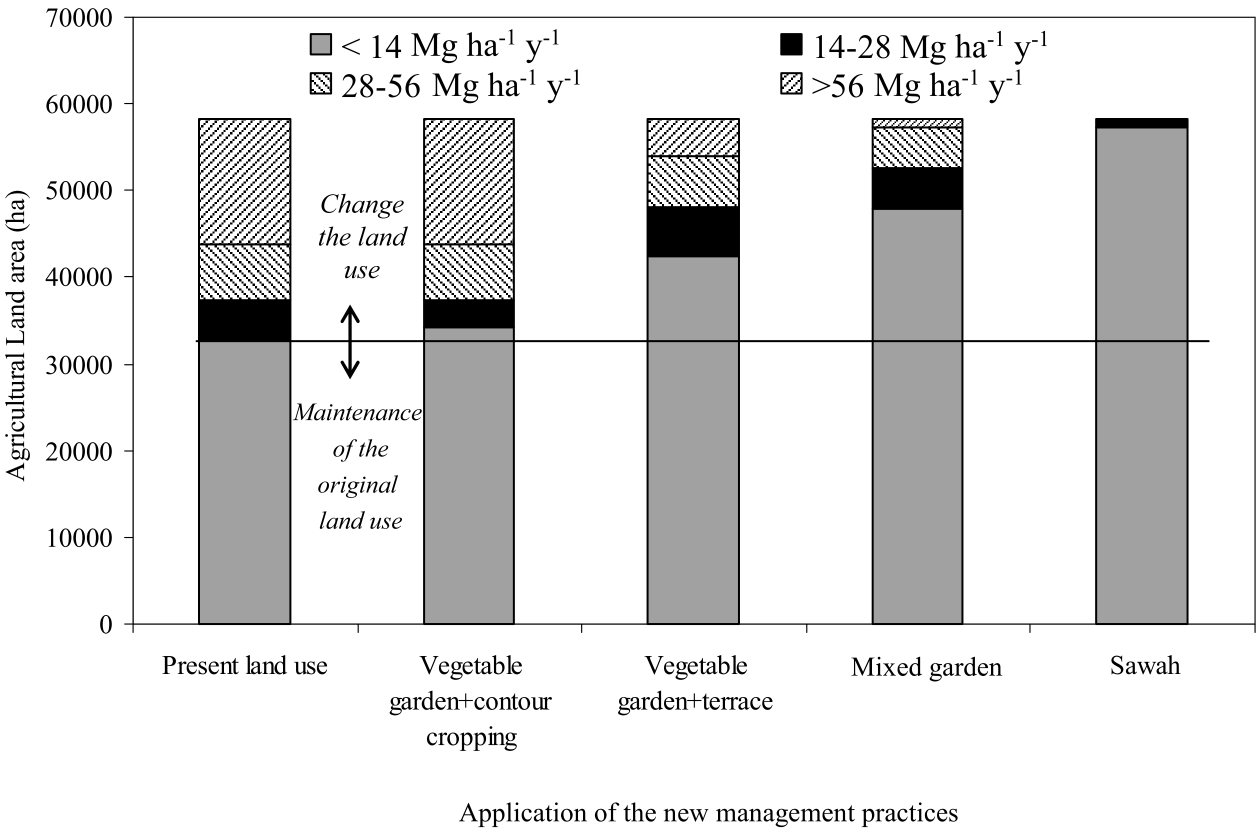

Fig. 3. Effect of respective agricultural land use types on controlling soil erosion rates in the Sumani watershed. This is a simulation assuming that all the area in the watershed, except forest is converted to respective land use types, except "Present land use". Total watershed area is 58330 ha.

RESULTS AND DISCUSSION

Results of economic feasibility analysis

The results of the economic feasibility analysis are shown in Table 1. The benefit was highest in vegetable gardens, which was approximately three to four times greater than sawah and mixed gardens. Farmers prefer to cultivate vegetables because of the higher economic benefit, however suitable areas to grow vegetable gardens are limited. Gardens require a cooler climate, which are only located in higher topographical positions. Vegetable gardens occupied approximately 25% of the entire watershed area (Table 2). Benefit-cost (B/C) ratio ranged from 1.84 to 6.15, which was higher relative to vegetable gardens in the Cianjur watershed (B/C ratio of 1.1) of central West Java (Sarainsong et al. 2007). Revenues were comparable in the Cianjur and Sumani watersheds, however production costs were three times higher in the Cianjur because farmers do not own land and must rent from land-owners. The cost for vegetable production in the Cianjur watershed was approximately U.S. $ 3,132 ha^{-1} y^{-1} with an average B/C ratio of 1.1 (Sarainsong et al. 2007). The costs in the Sumani watershed were U.S. $ 1,051 $ha^{-1} y^{-1}$ with an average B/C ratio of 3.28 (Table 1). This indicates that land costs must be considered in production, and lower benefits and B/C ratios are expected in regions such as the Cianjur watershed. In the Sumani watershed, sawah in all sub-watersheds exhibited soil erosion rates less than the TER. Rice is only harvested once a year in S1 and S2 sawah located in the middle to upper topographical positions. Despite one harvest per year, S1 and S2 showed a higher B/C ratio than lowland sawah at S3 and S4 where farmers harvest two or three times a year. This is largely due to rice quality. S1 and S2 rice quality is considered better, likely due to the cooler climate. Therefore, consumers preferred it resulting in a higher selling price than S3 and S4 lowland rice. Vegetable gardens exhibited very high soil erosion rates, i.e. 132.3 Mg ha^{-1} y^{-1} on average due to locations on watershed slopes. Most vegetable gardens showed values less than the TER. Tomato gardens had high production and prices, resulting in increased B/C ratios compared to peppers, radishes, small red onions (*bawang merah* in Indonesian) and other vegetables. In mixed gardens, coconuts showed a higher B/C ratio than that of duku (*Lansium domesticum* Corrìa [Meilaceae]).

Our study clearly demonstrates a large difference in the benefit to different land uses. Therefore, we must maintain vegetable gardens to continue generating suitable agricultural profits in the Sumani watershed. Similar considerations must be extended to other watersheds when applying our recommended land use planning.

Recommended land use planning

A simulation study was conducted assuming all the watershed areas, with the exception of forest, was converted to each different land use type, and did not remain under its own "present land use". The simulation applied a single land use type to simulate control of soil erosion rates on an area where the soil erosion rate exceeded the TER (Fig. 3). The application of soil conservation practices such as contour cropping and terracing to vegetable gardens was an effective means to reduce the soil erosion rate below the TER. A respective 59% and 73% decrease in soil erosion below the TER for the entire watershed was observed when contour cropping and terracing were adopted. However, due to the mountainous topography and high annual rainfall in the Sumani watershed, these conservation practices were not sufficient to control soil erosion in all the agricultural lands. Mixed gardens and sawah were more effective in reducing soil erosion rates in the watershed. This is congruent with past research conducted in Indonesia, which demonstrated that mixed gardens and sawah were best suited to reducing soil erosion and increasing crop productivity (Kusumandari and Mitchell 1997). Mixed gardens and sawah were shown to reduce soil erosion rates in wider areas, approximately 82% and 98% of the total watershed area, respectively. Mixed gardens and sawah exhibited a greater potential to control soil erosion due to lower *CP*-factors compared with vegetable gardens. The *CP*-factor of mixed gardens, sawah and vegetable gardens were 0.01-0.08, 0.003-0.009 and 0.2, respectively. Plants grown in mixed gardens have multilayered canopies. The lowest layer serves as an effective ground cover, protecting the soil surface from disturbance by intense and prolonged rainfall. Sawah has soil ridge surrounding the area, which controls soil erosion and run off. As we previously stated, in terms of the greatest economical profit/benefit to the Sumani watershed area, vegetable gardens are the preferred option, followed by mixed gardens or sawah (Table 1). Reforestation must be applied to sloping areas to control high soil erosion rates in all areas exceeding the TER.

The predicted soil erosion rates under watershed recommended land use planning is shown in Figure 4. Data summarizing soil erosion rates, percent cover of

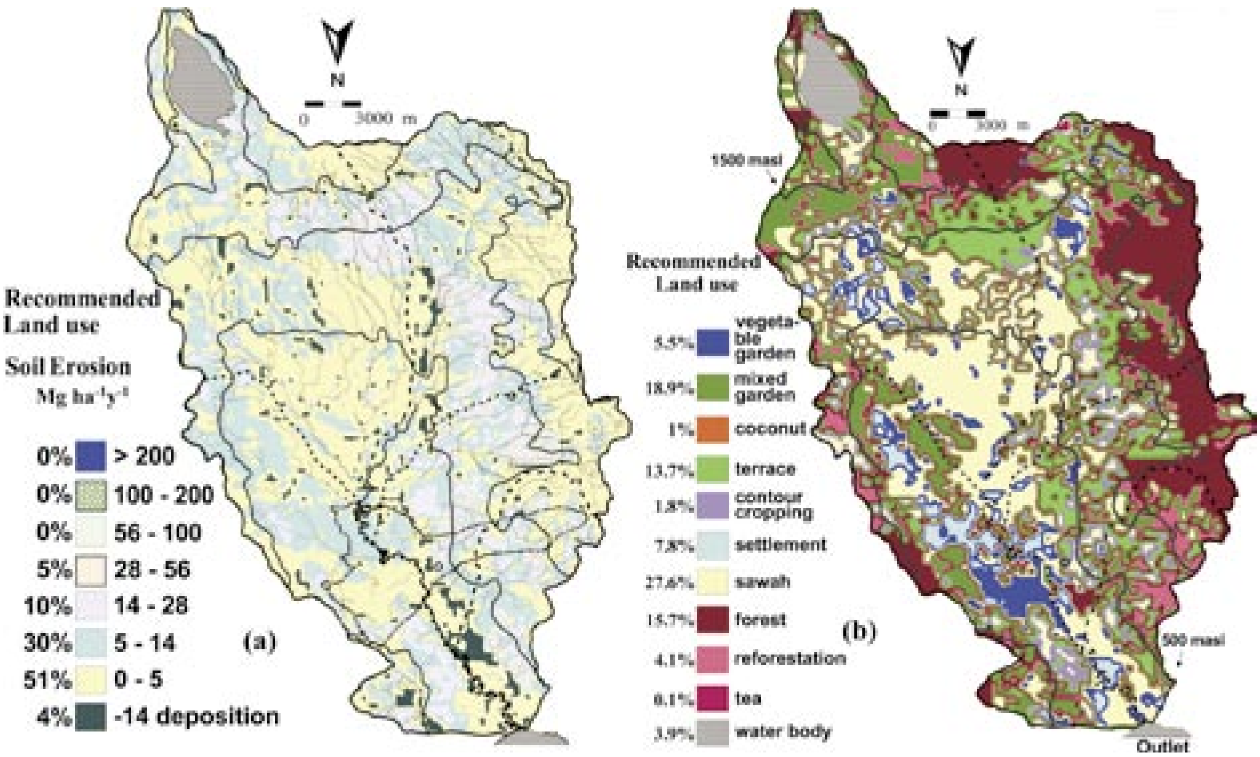

Fig. 4. Predicted soil erosion rate (a) under Recommended land use pattern (b)

land use types and benefit from agricultural production in the current and recommended land use planning is provided in Table 2. The predicted soil erosion rate under the recommended land use planning was 7.1 Mg ha^{-1} y^{-1}, accounting for an 86% reduction in the present land use condition. In the recommended land use, surface coverage of vegetable gardens with contour cropping and terracing, mixed gardens with full cover crops and sawah were 1.8, 10.0, 19.0 and 27.6% with increments of 1.8, 10.0, 6.8 and 4.3% from the present land use conditions, respectively (Fig. 4 and Table 2). Zhang et al. (2003) reported that terracing vegetable gardens is an effective measure to reduce erosional processes in the Sumani watershed. Terracing is an effective method of soil conservation on steep slopes and has been used extensively to control water erosion in hilly areas by farmers in many countries.

By applying the recommended land use planning to the watershed, we expected a large reduction in the soil erosion rate with a very small reduction in the agro-economic profit i.e. 3.9% from that in the present land use condition. The change was from 66.85 million US$ in current land use condition to 64.26 US$ following the land use change. In the present study, although we did not consider an option that included a sawah rotation to increase profitability, it is feasible. In fact, in upper topographical positions in the watershed, some farmers have practiced a rotation of rice and vegetables. However, some farmers converted their land from sawah exclusively to vegetable gardens to increase their agro-economic income, which resulted in an increase in soil erosion. Such demands on farmers must be considered in planning implementation. It may be most practical and effective to cultivate vegetables during the dryer season and rice in the wetter season to control soil erosion and ensure the farmers the most reliable and profitable income. However, this is contingent on seasonality. Our climate data in the Sumani watershed showed a recent atypical absence of seasons.

Obviously, it is not possible to implement the recommended land use planning at one time. Agus et al. (1997) and Crasswell et al. (1997) report that continued use of appropriate agronomic practices is preferable to reduce soil erosion with low cost whenever possible. Therefore, we should proceed with the application of better watershed management practices step by step. In fact, land use conversion is inevitable to practice agriculture on very steep slopes and farmers practiced it, even though the government and/or researchers did not pressure farmers to take steps to make necessary changes (Svoray et al. 2005, Sarainsong et al. 2007). This means natural motivation to apply soil conservation practices in the area was in place. The government and researchers must provide appropriate information to advise farmers and/or the local government regarding appropriate watershed management. The recommended land use planning in the present study is a practical example of what can be provided.

In this recommended land use planning, reforestation was applied to sites with bush (grass, shrub and *alang-alang*) and some sites with mixed gardens on the very steepest slopes. Reforestation was most suitable because these sites are not productive in the present land use condition and tree planting has been a common practice in mixed gardens. In contrast, soil conservation practices such as contour cropping and terracing in vegetable gardens are rather difficult because the approach is costly and requires new skills for farmers. Incentives or subsidies to farmers from the central or local governments and other sectors, such as the National Electricity Agency, which are stakeholders of the Sumani watershed management, may be necessary to execute the recommended land use planning. Stevenson and Lee (2001) and Sarainsong et al. (2007) report that the strategies and management activities should be discussed and refined by local people, government and other stakeholders before planning implementation.

ACKNOWLEDGEMENTS This study was supported by Japan Society for the Promotion of Science (Grant-in-Aid Scientific Research No. 18405043 and No. 19002001). I also thank to Indonesia Directorate of Higher Education Department with Ministry of National Education, Indonesia and National Polytechnic of Agriculture Payakumbuh for academic supports of my study in Japan.

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Received 28th Jan. 2010
Accepted 25th May 2010