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REVIEW

Hilly-Land Soil Loss Equation (HSLE) for Evaluation of Soil Erosion Caused by the Abandonment of Agricultural Practices

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Abstract

Soil erosion from fields located in the hilly lands of Shikoku was investigated. These are the areas where agricultural practices are quite limited and fields are often left idle and unutilized. Based on the results of the investigation, the calculated soil loss in terraced paddy fields and upland fields was about 3 t $ha^{-1}y^{-1}$ and 8 t $ha^{-1}y^{-1}$, respectively. Large soil loss (about 90 t $ha^{-1}y^{-1}$) was calculated to occur within several years immediately after abandoning cultivation of fields. Though soil loss did not largely increase in fields which changed to mowed grass fields (about 12 t $ha^{-1}y^{-1}$), there was a significant increase in mowed grass fields which changed to wild fields (about 40 t $ha^{-1}y^{-1}$). Soil loss in wild fields which were not cultivated for more than 6 years, decreased and became relatively stable (about 10 t $ha^{-1}y^{-1}$). To estimate the potential soil erosion of abandoned fields which are no longer cultivated, the Universal Soil Loss Equation (USLE) was revised to create the Hilly-land Soil Loss Equation (HSLE) by the addition of a term related to the erosion caused by intrusive surface and shallow-underground water runoff.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: potential soil erosion, shallow groundwater

Introduction

Around 40% of the agricultural land in Japan is located in mountainous areas. Their production accounts for more than 30% of the total agricultural production and sustains the lives of the inhabitants in rural regions. Around 14% of rice fields and 40% of upland fields are located on sloping lands steeper than 5 degrees. These sloping fields have sustained use with little erosion for long periods, because surface mulching, terraces, roads, and water canals are well managed by farmers. When management of the sloping fields is abandoned, soil erosion occurs. Field structures such as bench terraces, banks, roads and canals become the causes of erosion especially on steep slopes, even though these field structures were constructed for the control of surface water and conservation of slopes with agriculture use.

In Japan, poor management and abandoning cultivation of sloping agricultural fields are regarded as major contributors to increasing soil erosion. Therefore, evaluation of soil erosion caused by changes in management of sloping agricultural fields has become increasingly necessary and important.

A well-known equation for predicting soil loss is the Universal Soil Loss Equation (USLE)[17]. The equation was created from soil erosion test data covering about 22 years in the United States, and has been effectively used for soil erosion calculation. The USLE has been applied and tested in many areas of the world, and sometimes is

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used with modifications. Modified USLE in Japan have been used, such as the equation revised in the "Land Resources Project"[7] and the equation with modified parameters by Taneda[15]. In the United States, the RUSLE (Revised USLE)[9] which also has been proposed is commonly used. The RUSLE is modified in some ways, such as a change in the rainfall factor for the western part of America, a reduction effect in the rainfall factor in flooded soils, seasonal changes in the soil factor, and a combined crop factor with 4 subfactors. However, most of the predictions by RUSLE are similar to the USLE. The Water Erosion Prediction Project (WEPP)[4] developed a simulation model which predicts the daily soil erosion by renewing the characteristic factors for plants and soil, and is still under improvement. However, the model is excessively complicated by an overemphasis on physical factors, large amounts of data are needed, and computer software is required. Therefore, the WEPP equation is not used in Japan.

Increased soil erosion caused by abandoning cultivation of agricultural fields was rarely reported. One which we could find was the increased soil erosion which occurred after changing terraced paddy fields to orchards, forest or abandoned fields in the upper watershed of the Monobe River[2]. The hydrologic conditions and location of agricultural fields contribute to increasing soil erosion when field conservation management practices, such as checks of channels and mulching are abandoned. Predictions of soil erosion with respect to the location of agricultural fields have been reported in very few cases. Moore and Burch (1986)[6] introduced the field length and inclining factors using the coefficient $a = A/bl$, which is applicable to uneven catchments. The variables are A: catchment area, b: width of contour lines, and l: depth or length of the catchment; with $a<1$ in expanded catchment areas, and $a>1$ in depressed catchment areas. The equation was shown to be similar to the equation for LS in USLE when the catchment is a rectangle, $a = 1$. It was supposed to make the LS equation physically provable. However, the catchment corresponds to just the field area, and the inflowing water from outside was not taken into consideration as a potential cause of soil erosion.

In this study, soil erosion was surveyed in a part of the Minamiogawa River catchment in Kochi Prefecture, and the changes in soil erosion with changes in field management were evaluated. Thereafter, a soil loss predicting equation for agricultural fields in hilly lands was devised on the basis of the calculated soil erosion in the investigated area, soil erosion experiments, rain simulator experiments, and published reports.

Methods

1. Survey of land use and soil erosion

The field survey was conducted in 1995 in Otoyo, Kochi Prefecture. Annual precipitation in the area was about 3,000 mm, and agricultural fields were located on a 15–25° mountain slope ranging in altitude from 400 m to 850–1,000 m from the river to the ridge line. Small dells carve the mountain slopes at 20–100 m intervals. Mother rock is crystalline and 7 soil series are distributed in this area. Land use management, and changes in the soil surface by soil erosion were surveyed in the model area. In a detailed investigation area of 0.43 km^2 in the model area, eroded soil was quantified for every field. The accumulated soil mass by the side-slopes in the lower paddy field, and soil mass lost via rill and gully erosion were estimated using information on soil mass returned to the field and land use history. Furthermore, aerial photographs in 2 different years were traced to analyze the change in land use.

2. Development of a soil loss evaluation equation for agricultural fields in hilly lands

The components of the soil loss evaluation equation for agricultural fields in hilly lands, i.e. Hilly-land Soil Loss Equation (HSLE), were considered. Parameters for mulching effect, sloping effect, and soil factors were determined by soil erosion tests, rain simulator experiments, and reported papers.

Results

1. Survey of land use and soil erosion

Fig. 1 shows the occurrence of soil erosion with the river system in the model area. Sheet erosion and uneven surfaces occurred in the river-side and/or depressed areas. Rain water infiltrated diffusively in surged slopes, and on the other hand, rainfall concentrated in the depressed slopes which induced surface and shallow-underground water flow in the lower parts of slopes producing soil loss. Rill erosion occurred in portions without mulching by an influx of water from upper fields or paved roads.

Springs were apt to appear at the top of the dells. Soil erosion progressed with the unsuitable treatment of rill, gully, and water channels induced by the inflowing water from upper areas etc.

The distribution of mowed grass fields and abandoned fields, the results of the soil erosion survey, and the springs occurring in the detailed investigated area are shown in Fig. 2 and Fig. 3. Soil erosion was apt to progress in fields with poor soil management, fields in lower parts of the mountain slopes, and fields near dells.

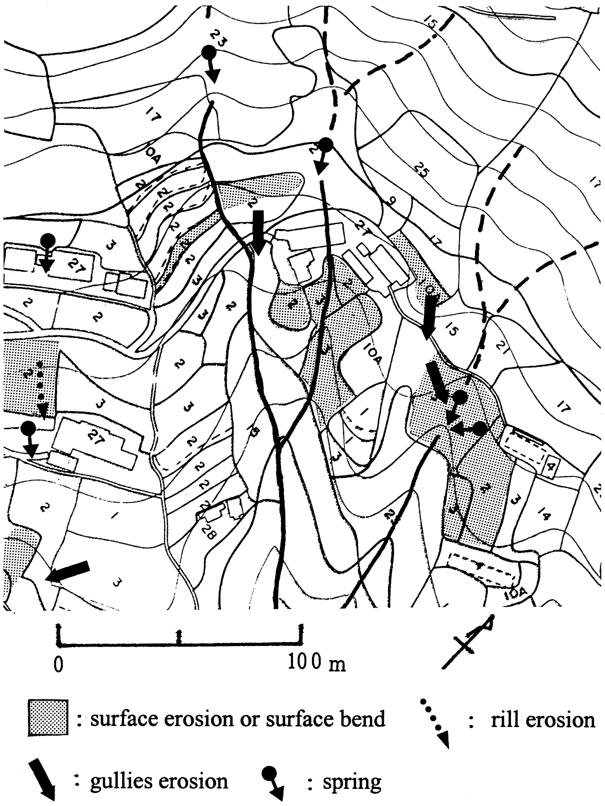

Fig. 1. Soil erosion in a part of the investigated area in Otoyo, Kochi

Numbers in Figure describe land use.

1:paddy rice, 2:general upland field, 3:edible wild plant, 4:green house, 5:fallow, 6:orchard, 9:bamboo, 10A:mowing grass, 11:abandoned, 13–25:forest, 27:land for house, 28:land for business.

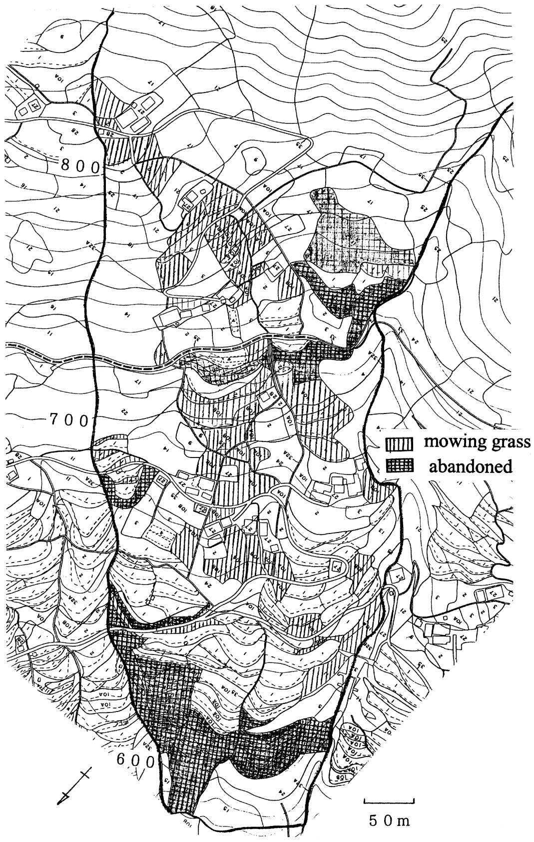

Fig. 2. Distribution of abandoned fields

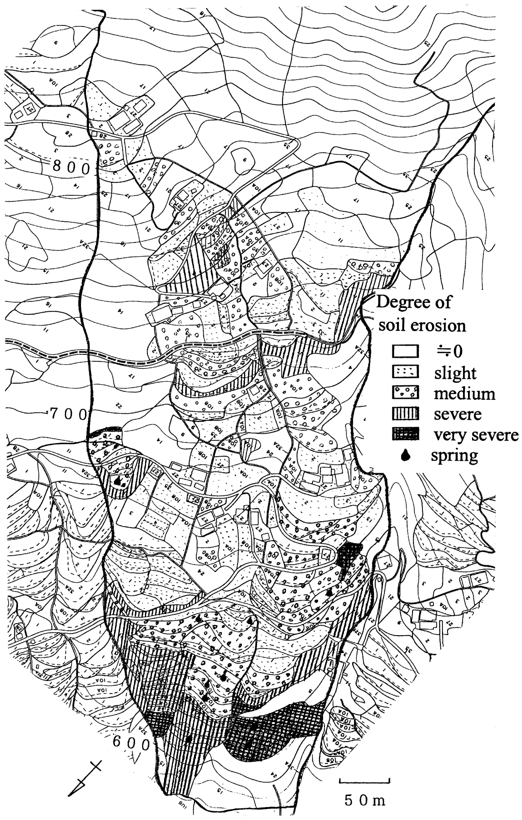

Fig. 3. Soil erosion in the investigated area

These results demonstrate the need for geographical and management factors to be incorporated into the HSLE.

Soil losses quantified by the survey were divided by year length while present land use continued. Year lengths were estimated from aerial photographs taken in 1989 and 1995, in addition to information from farmers as follows.

(Land use in 1989)	(Land use in 1995)	(Year length while present land use continued)
mowing grass	mowing grass	8
mowing grass	abandoned	6
abandoned	abandoned	20
paddy rice, upland	mowing grass	6
paddy rice, upland	abandoned	6
paddy rice, upland	paddy rice, upland	50
mowing grass	paddy rice, upland	6

Soil losses in arable fields were small apparently because of treatments such as compensating for rills and gullies and returning soil to the fields. Replaced soil was estimated to be about 200 kg per 10 m for the lower ridge of sloping upland fields. Therefore, about 8 t ha^{-1} y^{-1} of soil was calculated to be replaced by taking 21 m of average slope length into consideration. In terraced paddy fields and terraced upland fields, 0.5–1 m^3 of soil was estimated to be broken down per 5 fields. Therefore in terraced fields, we calculated that 2 t ha^{-1} y^{-1} of soil was returned, by taking the average 590 m^2 terraced field area into consideration. The soil loss from arable fields should be the net total of apparent soil loss and returned soil. Soil losses calculated by each land use are shown in Fig. 4, and the calculated soil loss per year is shown in Table 1.

The calculated soil loss in the terraced paddy fields and upland fields was about 3 t $ha^{-1}y^{-1}$ and 8 t $ha^{-1}y^{-1}$, respectively. Those values are the sum of apparent soil loss (less than 1 t $ha^{-1}y^{-1}$) and average soil mass returned to fields. Large soil loss (about 90 t $ha^{-1}y^{-1}$) was calculated to occur within several years immediately after abandoning cultivation of fields. Though soil loss did not largely increase in fields which became mown grass fields (about 12 t $ha^{-1}y^{-1}$), there was a significant increase in mown grass fields which became wild fields (about 40 t $ha^{-1}y^{-1}$). Soil loss in wild fields which had not been cultivated for more than 6 years, decreased to relatively stable levels (about 10 t $ha^{-1}y^{-1}$).

Large soil loss occurred for several years immediately after abandoning cultivation of arable fields (paddy rice, upland crops and grass). The soil losses measured in abandoned fields were larger than those measured in the frame plots (Table 2). Although the soil loss values in Tables 1 and 2 cannot be directly compared, the role of surface and shallow-underground water flowing into the zones was regarded as a main cause of soil erosion. It was frequently observed that water overflowing from plugged canal ditches intruded into abandoned fields.

2. Development of a soil loss evaluation equation for agricultural fields in hilly lands

(1) Composition of the equation

Revision of the USLE was made using information from several experiments, verbal descriptions of land use history, and reported papers. In order to estimate the potential soil erosion on terraced fields when they had been abandoned and no longer cultivated, the Universal Soil Loss Equation (USLE) was revised by the addition of a term related to the erosion caused by intrusive surface and shallow-underground water. The original USLE is written as follows:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (1)$$

where:

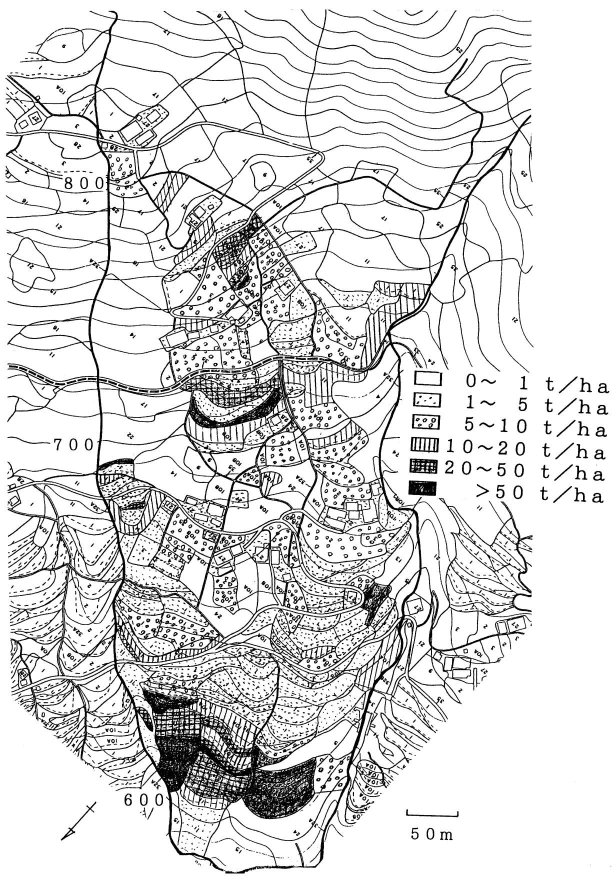

Fig. 4. Soil erosion estimated by field measurement and information from farmers

A = the soil loss (t ha^{-1}),
R = the rainfall-runoff erosivity factor (tf m^2 ha^{-1} h^{-1}),
K = the soil erodibility factor (t h tf^{-1} m^{-2}),
L = the slope length factor,
S = the slope-steepness gradient factor,
C = the cover management factor,
P = the support practice factor.

This equation predicts soil loss caused by the erosive forces produced within the field and does not take into consideration the intrusion of surface and shallow-underground water from outside the field. The new erosion equation, Hilly-land Soil Loss Equation (HSLE), consists of the USLE term for the terrace (flat surface + slope) and a term for the influence of intrusive water inflows:

$$A = I \cdot K \cdot [E \cdot \{L \cdot S \cdot C \cdot P \cdot r_s + L' \cdot S' \cdot C' \cdot P' \cdot (1-r_s)\} + f_a \cdot M \cdot Z \cdot C \cdot P] \qquad (2)$$

where:

f_a = parameter related to erosivity of intruded surface and shallow-underground water,
M = intruded surface and shallow-underground water related to catchment area (tf ha^{-1}),
Z = height between two terraces (m),
r_s = side-slope ratio; r_s=1 for sloping field, r_s of

Table 1. Annual soil loss estimated from field survey and information from farmers

Land use in 1989	Land use in 1995	Ratio of area occupied (%)	Apparent annual soil loss (t ha^{-1})	Annual returned soil (t ha^{-1})	Annual soil loss (t ha^{-1})
Mowing grass	Mowing grass	4.7	7.2		7.2
Abandoned	Abandoned	5.8	10.1		10.1
Mowing grass	Abandoned	0.8	43.2		43.2
Paddy rice / Upland field / Fallow	Abandoned	1.8	92.7		92.7
Paddy rice	Mowing grass	2.4	11.9		11.9
Upland field	Mowing grass	1.2	11.4		11.4
Paddy rice	Paddy rice	7.6	0.8	2.0	2.8
Upland field	Upland field	4.2	0.3	8.0	8.3
Paddy rice	Upland field	0.7	0.1	8.0	8.1
Upland field	Paddy rice	0.3	0.1	2.0	2.1
House/business	House/business	3.1	0.1	2.0	2.1
Forest	Forest	66.5			
Others	Others	0.9			

side-slope and $(1–r_s)$ of flat surface for terraced field.

In HSLE, the rainfall factor R of USLE was partitioned into rain energy and rain intensity. Also in HSLE the USLE type terms for the slope-side and the flat surface, and the term for contribution of intruding surface and shallow-underground water induced by abandonment of conservative management are set parallel.

The contribution term for intruding surface and shallow-underground water is composed of the product of potential energy and rain intensity. Though intruding running water is supposed to increase while flowing down the field, its increase in the field is already included in the USLE type terms. Therefore, the mass of intruding surface and shallow-underground water is assumed to be constant. The velocity of intruding surface and shallow-underground water is assumed to be constant under conditions of constant slope steepness, surface coarseness, and water depth. Also, the difference in the potential energy of intruding surface and shallow-underground water between the top and bottom levels of the field contribute to soil erosion. Rainfall intensity was substituted for velocity of the intruding surface and shallow-underground water as an approximation[3,10]. The intruding surface and shallow-underground water is formulated as followed:

$$M = r\ w\ d\ f_{(H)}/a \qquad (3)$$

r : annual precipitation (total of >13 mm rain corresponding to R in USLE)
w : weight of water per unit volume (tf m^{-3})
d : catchment area (m^2)
$f_{(H)}$: ratio of surface runoff/precipitation
a : field area (m^2)

Table 2. Soil loss from abandoned plot and mulched plots (19 m × 5 m)[18]

Treatment	Slope (degree)	Annual soil loss (t ha^{-1})
Abandoned	14.6	13.5
Grass mulch 3 t ha^{-1}	14.9	0.10
Grass mulch 10 t ha^{-1}	15.2	0.01

The catchment area, d, is large in depressed landforms and small in surged landforms. The $f_{(H)}$ is assumed to be $f_{(H)} = b \bullet H$ (b: coefficient, H: difference in altitude between the ridge and the field), because $f_{(H)}$ is assumed to increase in proportion to H. Here, b was determined so that the average $f_{(H)}$ of the mountain area becomes the annual flow rate. The annual rate of flow is the flow/precipitation. Here, the flow is the total of the direct flow, such as surface flow, shallow-underground flow, and base flow. The runoff coefficient is 0.7 for the Yoshino River[13], of which the Minamiogawa River is a branch. The $f_{(H)}$ depending on the field standing points in the mountain is described as follows:

$$\int_0^{H_{max}} f_{(H)} dH/H_{max} = \int_0^{H_{max}} b \bullet H\ dH/H_{max} = b \bullet H_{max}^2/2H_{max} = 0.7$$

$$\therefore\ b = 1.4/H_{max} \quad \therefore\ f_{(H)} = (H/H_{max}) \times 1.4 \qquad (4)$$

The field area "a" is described by a = wl, where w is field width and l is field length. The term M • Z contains the specific catchment area d/w, and the gradient expressed by $\tan\theta = Z/l$.

A coefficient "f_a" was introduced because the degree of intruding surface and shallow-underground water causing soil erosion varies with the degree of field management. In the equation, soil loss appears as the maximum soil loss, because soil inflows from the upper fields are not considered as described later.

(2) Parameters

(i) Factors R, E, I and r related to rainfall erosivity (how to devise R into E and I)

For HSLE, the individual E, and I, which are derived from the rainfall erosivity factor R, are calculated on the basis of rainfall data measured every 60 min. According to Fujihara et al.[1], R divided by t(h) is theoretically:

$$R/t = E/t = E'I = 10.7 \bullet I^{2.22} \qquad (5)$$

Here, the unit for E' is J m^{-2} h^{-1}, and unit for I is mm h^{-1}. The unit change for R is as follows:

$1\ tfm^2ha^{-1}h^{-1} = 9.8 \times 10^3 J\ m\ ha^{-1}h^{-1} = 9.8 \times 10^2 J\ mm\ m^{-2}\ h^{-1}$

The determination of I is a problem because the natural rainfall intensity is not constant. Miura[5] analyzed the AMEDAS rainfall data of 13 to 15 years for Motoyama, Odoti, and Shigeto near the model area according to Taneda[14] to determine R. The results of the study show the average accumulated rainfall which was effective to soil erosion (r = 2.61 m), the average rainfall erosivity factor (R_{60} = 1,251 tf m^2 $ha^{-1}h^{-1}$), the average accumulative rainfall time (t = 618 h), and the average maximum 60 minute rainfall intensity (I_{60} = 12.2 mm h^{-1}). By introducing these values into the equation (5), I = 10.5 mm h^{-1}, I = 0.86 I_{60}, and E = 1.191 × 10^5 tf m ha^{-1} were derived from $R = E \bullet I = E \bullet 0.0105$ m h^{-1}.

(ii) Slope length factor L

The equation proposed by the Agricultural Structure Improvement Bureau[8] is

$L = (l/20)^{0.5}$, where l: slope length(m) was used. This equation is almost identical to L in USLE.

(iii) Slope-steepness gradient factor S

The slope-steepness gradient factor S used in this study was

$$S = 0.38\ e^{0.0747\,\theta} + 0.447 \qquad (6)$$

which was determined by rainfall simulator experiments and the proposed equation by the Agricultural Structure Improvement Bureau[8]; $S = 0.38\ e^{0.075\,\theta} + 0.068$.

The rainfall simulator (nozzle type) was used to investigate raindrop distribution, kinetic energy, and other factors. The soil boxes used in the rainfall simulator tests were 1.0 m length, 0.3 m width, and 0.1 m depth from which infiltrated water drained smoothly. Tests in 10, 20, 30, 40, and 50° gradients were conducted with a duplication for the surface soil of one of the main soil series in the model area. Preparation of the soil box samples, investigation of the rain simulator, and detailed data are from Tokudome[16], and Yoshikawa et al.[19].

(iv) Soil erodibility factor K

Rainfall simulator tests were conducted using the same rainfall simulator and soil boxes described in section (iii) for the 7 soils in the model area and one soil in the field of the Center. The soil erodibility for these soils was calculated by dividing soil loss by the rainfall erosivity factor. The soil box preparation was the same as for section (iii). Relative soil erodibility for the 7 soil series and the field soil in the Center were calculated by dividing soil loss by USLE, shown in the equation (1). Here C and P are described in the next section (v). Thereafter, a realistic soil erodibility factor K was determined by multiplying the ratio of K_{field} [11,12]/$K_{\text{rainfall simulator}}$ for the soil in the Center. Soil erodibility values for K are shown in Table 3. Soil erodibility values for HSLE were smaller than those from USLE.

(v) Cover management factor C and support practice factor P

The cover management factor C and the support practice factor P were determined using reported values[7–9] and experiments[18] as shown in Table 4. The P of the slope-side of the fields was set at 0.5 because soil hardening or presence of stone walls decrease P values from 1.

(vi) Parameter related to intruded surface and shallow-underground water f_a

The parameter f_a was determined by using other factors determined already so that the soil loss evaluated by HSLE corresponds well to the investigated soil loss in the model area. As a result, f_a was about 1.0 for fields abandoned for several years, 0.2 for relatively stable wild fields or mown grass fields, and 0 for arable fields.

(3) Estimation of soil erosion by HSLE

Soil erosion as estimated by the USLE terms of HSLE is shown in Fig. 5. The difference in the estimated possible soil erosion for every field was too small to

Table 3. Soil erodibility factor K of 7 soil series distributed in the investigated area

Soil	Soil series	K
Brown forest soil	Tsunoyama-2	0.041
	Tsunoyama-3	0.099
	Takebeta	0.121
Humid brown forest soil	Tsunoyama-4	0.295
Volcanic ash soil	Daikokuyama	0.060
	Yusuhara	0.022
Brown lowland soil	Joman	0.049

Table 4. Cover management factor C and support practice factor P

Land use		C		P
Paddy rice	Flat plane	0.38[7]		0.6[8]
	Slope side (management)	0.02[9]		0.5
	(abandoned)	0.04[17]		0.5
Upland field	Soybean	0.4[8]		Longitudinal ridge 1.0
	Corn	0.4[8]		Flat ridge 1.0
	Green pea	0.5[8]		Contour ridge 0.6
	Tomato	0.3[8]		Horizontal ridge
	Edible wild plant	0.3	*[8]	1–4° 0.27
				4–7° 0.30
	Mulching	0.05[8,18]		7–10° 0.40
				10–15° 0.45
				15–25° 0.50
Fallow		0.45[17]		by *
Orchard		0.34[7]		usually 0.6
Mowing grass		0.02[8]		1.0[8]
Abandoned		0.04[17]		by *
House/business		0.37[7]		1.0[8]

explain the actual large differences among agricultural fields. In the hill lands of Shikoku, soil erosion tended to proceed in the mown grass fields and cultivation-abandoned fields. However, USLE cannot calculate such severe soil erosion. The reasons are as follows: (1) The rainfall erosivity factor R, the slope length factor L, the slope gradient factor S, and the soil erodibility factor K do not change largely; (2) The cropping management factor C, which is related to the crop cover ratio is unavoidably small because of the high weed cover ratio; (3) The erosion control practice factor P excludes values of P>1 by reason of $0 \leqq P \leqq 1$ with $P = 1$ for flat level fields.

The soil erosion estimated by HSLE, which takes surface and shallow-underground inflow water into consideration as a contributor to soil erosion, is shown in Fig. 6. HSLE can account for the results of the present study where severe soil erosion occurred in lower parts of the mountain slopes and fields near dells. Furthermore, soil erosion increases following abandonment of cultivation can be explained by an increase in parameter f_a which shows the extent of inflowing water as a contributor to soil erosion. The soil erosion estimated by HSLE shown in Fig. 6 corresponds relatively well to the soil erosion estimated by the field survey shown in Fig. 4. To further improve accuracy, detailed investigation on soil physical properties and stratigraphic characteristics related to shallow-underground water flows will be required.

The contribution ratio of terms in equation (4) was analyzed as follows. The inflowing water contribution term was added for the 167 mown grass fields, wild fields, forest, and materials deposited from the 276 fields

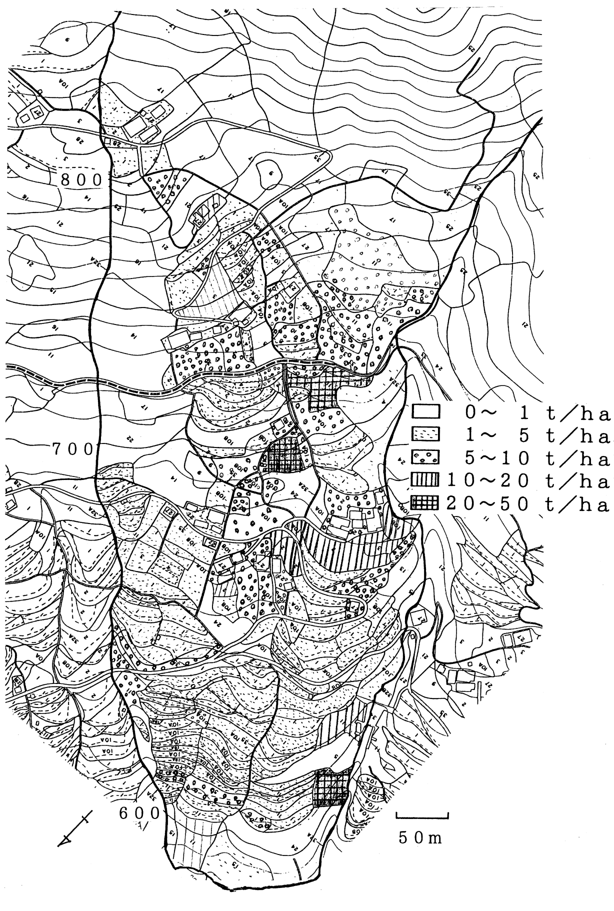

Fig. 5. Potential soil erosion estimated by the USLE type term

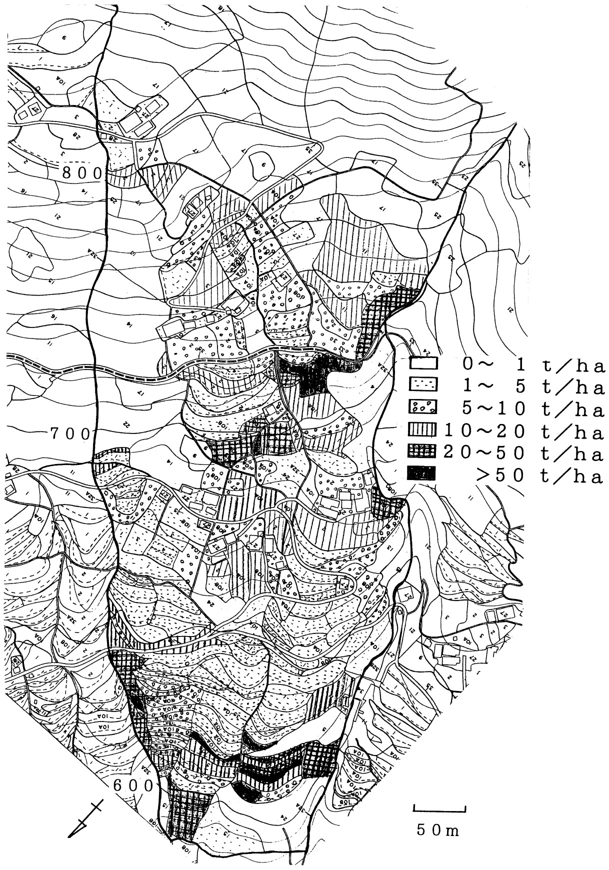

Fig. 6. Potential soil erosion estimated by HSLE

in the model area. The average contribution ratios were 53% from USLE-type terms and 47% from the intrusive inflowing water term. In 161 fields, which had paddy terraces, an average of 82% of soil erosion was calculated to occur on the slope-side, and an average 18% occurred on flat surfaces. The slope-side ratio was about 16% of the projected plane of fields with paddy terraces. Water catchment area/ field area was 15 on average for all 276 fields.

Discussion

In the field survey for land use and soil erosion, soil erosion was found to be severe in cultivation-abandoned fields. This is especially the case for several years just after abandonment of management practices, such as mowing grasses. Four reasons that soil erosion occurred in cultivation-abandoned fields despite the presence of vegetation were:

① increase of infiltration water and incidental shallow-underground water by looseness in the plow pan which results in the occurrence of soil erosion from inside;

② inflowing surface and shallow-underground water from outside promoted by the destruction of irrigation and drainage canals;

③ the development of rill, gully, and water channels induced by unevenness in binding soil strength of vegetation where surface-water runoff occurs;

④ unrepaired water channels induced by unevenness in surface-water runoff and holes made by moles.

The parameter f_a shows the contribution of intrusive inflowing water to soil erosion. Severe soil erosion appears to be induced by the intrusion of surface and shallow-underground water in abandoned fields as a result of the above 4 conditions.

On mountain slopes, soil erosion resulted from surface-runoff water which sometimes goes underground and later returns to the soil surface, and by shallow-underground water which sometimes exits the soil surface and returns underground. Therefore, the inflowing water from outside which contributes to soil erosion is thought to be surface-runoff water, including shallow-underground water. HSLE estimated the maximum soil erosion from one field. In the area of arranged terraced fields, it was sometimes observed that the inflowing soil mass from upper fields is almost equal to the outflowing soil mass to lower fields. In most of the cases, farmers have to move soil from the mountainous ridge side to the valley side to make the field surface flat.

Future research should consider the following points: (1) This study was conducted in hill lands in the center of Shikoku where the base rock is crystalline rock. (2) In this area, though land-slides are thought to be another contributor to soil erosion, it is difficult to distinguish between soil erosion caused by rainfall and land-slides. Therefore, the possibility that anthropogenic soil erosion was overestimated is unknown. The verification of HSLE (under appropriately varying f_a) in areas free from land-slides is necessary. (3) In the study area, snow is rare. Further study is needed in areas where melting snow contributes to soil erosion.

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